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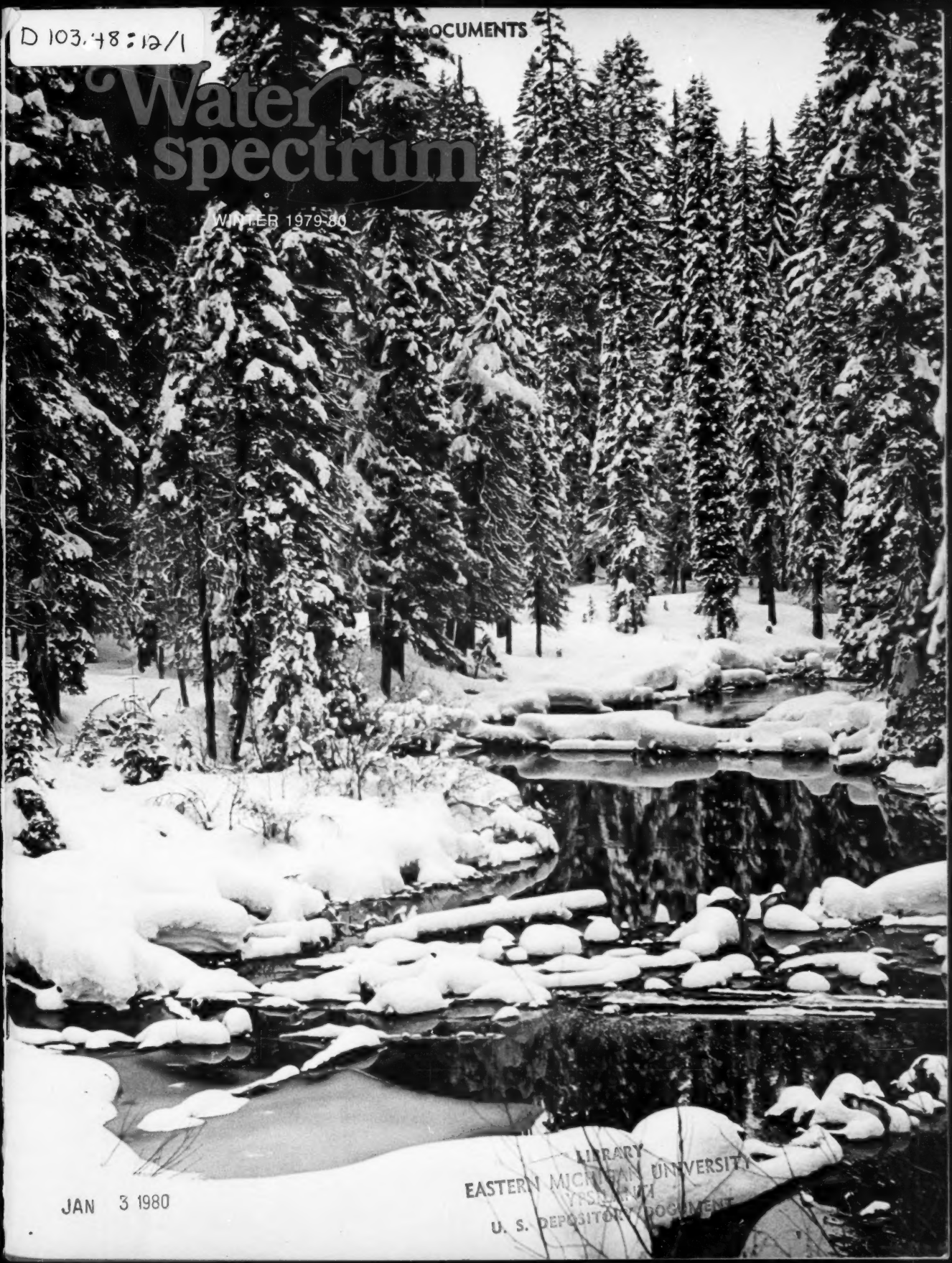

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# Water spectrum

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Comments on topics in this publication are invited. Send to:
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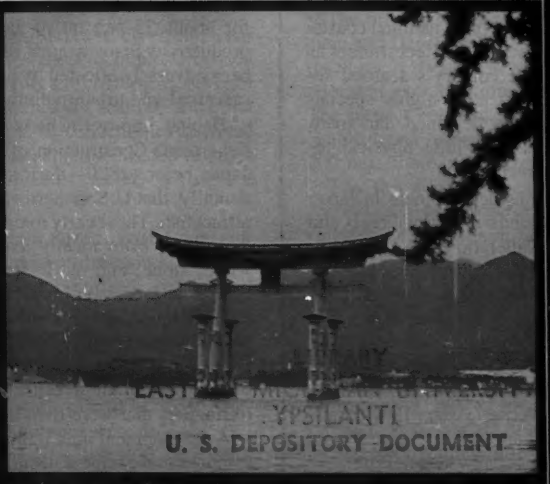
COVER: *Announced by all the trumpets of the sky,*
*Arrives the snow.—Ralph Waldo Emerson*
*(Photo by Bruce Berg)*

# fisheries development: Japan




by Daniel J. Sheehy

Discarded tires, wrecked automobiles, beer cans filled with concrete—these are some of the materials that have been intentionally submerged off the U. S. coast to form artificial reefs and improve fishing grounds. Fishermen have long observed that fish tend to congregate in areas where natural reefs, submerged trees, rocks, or sunken ships create rough bottom conditions and offer shelter from currents and predator species, and provide food by promoting the growth of algae, barnacles, and other marine life. Artificial reefs can perform the same function.

*Dr. Sheehy is a fishery biologist with Aquabio, Inc., of Belleair Bluffs, Florida 33540. He formerly directed the artificial lobster reef program at the Graduate School of Oceanography of the University of Rhode Island.* *This article is based on a research trip to Japan sponsored by a grant from the Japan Society for the Promotion of Science.*

Most artificial reefs in U.S. coastal waters are made from weighted scraps that are placed on the ocean floor where they attract groundfish and crustaceans. They are marked with buoys and are used primarily by sports fishermen. State and local governments and recreational fishing clubs usually fund the reefs and the Corps of Engineers ensures that their placement will not interfere with commercial fishing or navigation. Even though they have proven popular with sports fishermen and their effectiveness in attracting sea life has been confirmed in studies conducted by the National Marine Fisheries Service and university oceanographers, artificial reefs play only a minor role in fisheries development in this country.

In Japan, however, artificial reefs receive major emphasis and funding because of their importance to current methods of habitat improvement, which a seven-year national coastal resource development program presently in effect stresses as a promising means of meeting the country's seafood requirements. The structurally sophisticated, highly specialized reefs which the Japanese have designed and manufactured as habitat improvement bear little physical resemblance to their American counterparts.

Habitat improvement for fisheries development in Japan goes beyond the construction of standard artificial reefs and includes a variety of structures and alterations which contribute to increasing coastal fisheries and aquacultural production. Included in the structures are moored surface and midwater fish attractors, as well as shelters designed to increase specific species of seaweed and invertebrates such as abalone and lobster, and to serve as nursery areas for hatchery-reared juveniles. Also included are measures to alter the substrate conditions (blasting, scraping, covering), water flow (channels enlarged or constructed) or to dampen the adverse effects of waves (floating or submerged breakwaters). Programs aimed at altering species composition to eliminate predators, minimize competition, or stock highly valued species for culture-based fisheries also come under the scope of habitat improvement.

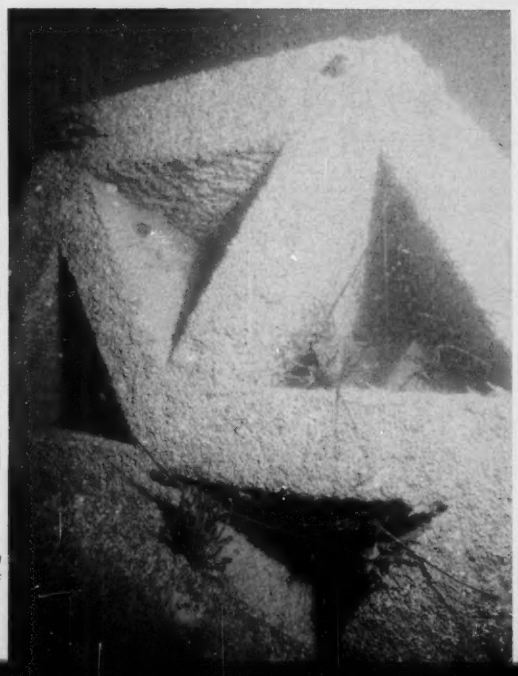
While all these techniques are currently being used in Japan, some of the more recent progress and emphasis has been placed on artificial reefs for both fish and invertebrates. These reefs are often used in conjunction with other techniques such as stocking, predator management, and supplemental feeding programs.

The Japanese depend on the sea for more than half their supply of animal protein and have the highest annual per capita consumption of seafood in the world—74kg/person. Although Japan also leads the world in commercial fisheries landings, several developments in recent years have stimulated the need to increase productivity in the surrounding coastal waters. Most notably, the 200-mile limits adopted by a number of countries have imposed costly restrictions on Japan's distant water fisheries which previously accounted for about 35 percent of Japan's total catch. In addition, productivity in many areas of Japan's own coastal waters had been adversely affected by overfishing for premium species, industrial and urban pollution, and land reclamation.

Habitat improvement is by no means new to Japanese fishermen. Construction of artificial fish shelters began in Japan before 1800—during about the same period, coincidentally, that U.S. fishermen also started building shelters to attract fish. These early forerunners of modern Japanese reefs were built from locally available scrap materials such as wood, stone, and old boats. When they proved quite successful in increasing productivity, their use spread. By the end of the century, in a move which pointed to the variety of functions which reefs presently perform in habitat improvement, local fishermen began also to use the shelters as barriers—to limit overfishing from the modern trawling techniques that were then being introduced.

A development important to the future structure of coastal resource management occurred in the early 1900s when collective efforts at reef construction by fishermens' cooperatives and villages began to supersede the piecemeal operations previously carried out by individuals. Much of the rapid technological advancement in reef construction and fisheries

*Adult abalone shelter unit in place at Taise. Note plastic attachments for seaweed. (Photo courtesy of Dr. Sato, Hokkaido University.)*



*Lobster reef units used in Miyazaki. (Photo courtesy of Mr. Uchida)*

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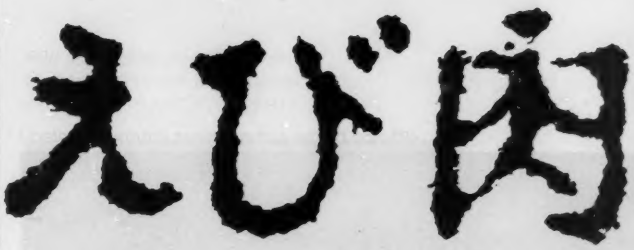
development during recent decades has been made possible by the carefully coordinated, nationwide cooperation between the government, fishing cooperatives (to which virtually all fishermen belong) and scientists at regional, prefectural, and university laboratories and equipment stations.. The national government currently provides about 60 percent of the funding for larger projects, with the remainder coming from prefectural and municipal governments and local fishing cooperatives.

Since 1952, fisheries development has been carried out through a series of long-term national programs. By coordinating a number of diversified projects, these programs have altered the nature of coastal fisheries and have contributed to appreciably increasing the income of coastal fishermen.

Improvement of grounds and resources received emphasis during the 1950s in projects designed to improve coastal habitat by removing unsuitable reefs and creating new shelter areas; to improve cultivation grounds for scallops and other shellfish; to provide facilities for the collection of seaweed (*nori*) spores; and to develop the expertise needed to stock and transplant juveniles of valuable species of fish and shellfish.

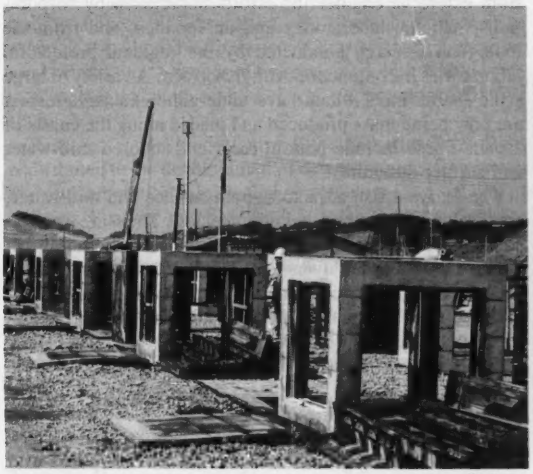
From 1962-1975, projects emphasized coastal aquacultural development and involved the construction of artificial mass culture facilities for shellfish and seaweed, aquacultural pens for open water fish culture, wave-damping breakwaters, and waterways to improve water exchange in inner bays. Improvements continued to be made in shelter design, and the use of specially designed concrete blocks was expanded—more than a million were placed at over 3800 locations by 1970. Aquacultural grounds were dredged, cultivated, and fertilized, while predator and disease control were improved. Technical developments in seedling production and stocking of scallops, abalone, yellowtail, shrimp, salmon, and seaweeds established Japan as the world leader in marine culture.




## Present Program

The present seven-year Coastal Fishing Grounds Adjustment and Development Project, which began in 1976, is the result of a 1974 law in which the national government allocated over a billion dollars to enhance coastal fisheries. The project emphasizes habitat improvement as a way to enable Japan to meet its seafood requirements in an era of 200-mile limits and increasing fuel costs.

The thrust of the new project results from a careful reevaluation by Japanese scientists and economists of the viability and economic feasibility of some of the massive stocking projects undertaken during the past 15 years. While the technological advances of the 1960s and early 1970s made possible the mass production of juveniles of a number of species, the survival of the juveniles after stocking, and economic return generated by these programs, came under scrutiny. The fate of juveniles after stocking was considered to be a weak link in the production system, and the new program was designed to integrate some of the hatchery and habitat improvement projects and maximize the productive potential of the coastal zone. This new project expands the earlier "intensive" aquacultural activities in ponds, pens, or from rafts, to what is now commonly called "culture-based fisheries."



*Concrete cube used in earlier reef projects, taken in Chiba prefecture.*

*Chiba lobster reef unit is checked by an official of the Chiba Prefectural Fisheries Experiment Station.*

(Photos by the author unless otherwise noted.)

*Concrete jacks used to stabilize gravel at Tokushima.*

近海魚

The project has two basic aims: the construction of large-scale artificial reefs and banks for fish, and the improvement of bottom conditions for specific highly valued species such as abalone, lobster, sea urchin, sea cucumber, and a variety of seaweeds. The latter includes the construction of special nursery areas as well as the construction of wave damping devices and dredging for circulation improvement.

*"Tsukiiso" abalone shelters, FRP with stones, manufactured by Asahi Chemical International Ltd. (Photo courtesy of Dr. Ogawa)*

## Fishing Ground Construction—Artificial Reefs

Japanese fish shelters are commercially manufactured from reinforced concrete, steel, iron, or petroleum-based materials such FRP and PVC, according to designs resulting from extensive engineering efforts undertaken by corporations, national laboratories and universities, and from the biological research conducted by the regional prefectural laboratories in conjunction with fishermen. A variety of large scale shelter units which have undergone extensive testing are now being mass produced and placed along the coasts of Japan. These include bottom reefs and moored mid-water and surface structures.

The buoyant fish attractors, both surface and mid-water, are designed to attract pelagic species. They are used to concentrate fish, alter normal migratory routes, and attract fish to specific water layers to avoid pollutants. Some of the shelters are used in conjunction with feeding programs to increase their effectiveness. Generally the mid-water and surface structures are moored in water between 60 to 100 meters deep and some surface units are capable of being placed in water up to 200 meters deep.

Artificial reefs, termed *"gyosho"* in Japan, are placed either to expand existing natural reef areas or to create new commercial fishing grounds in areas which were previously sparse or marginally productive. Projects to expand existing grounds require a minimum site area of 2500 square meters,

while those to create new fishing areas or banks require a minimum of 20,000m². Most bottom shelters are located at depths between 30 and 60 meters, but some are placed as deep as 120. Sites are carefully chosen based on detailed physical, chemical, and biological studies, as well as practical considerations. Catch data are monitored to provide a data base for economic evaluation.

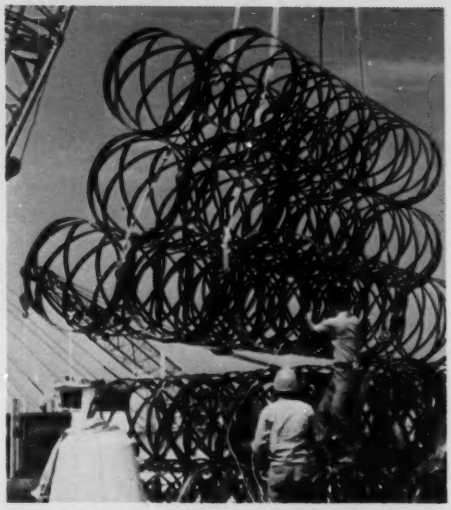
The Agricultural Civil Engineering Laboratory in Kanagawa Prefecture has been conducting studies on the hydraulic factors involved in reef placement and site selection. This research has provided some new ideas on how reefs function. When currents impinge on reefs, instabilities occur between vertically stratified fluid layers which generate internal waves. Studies demonstrated that the presence of internal waves significantly influences pelagic fish distributions. Acoustical observations indicate that fish concentrations correlate with the presence of lee waves resulting from the interaction of currents with the reefs. Results of these studies suggest that the aspect ratio (height of the reef to water depth) should be between 1/20 to 1/5, depending on local conditions. Other studies concerned with benthic fish indicate that the width of the reef is an important factor in fish abundance.

Research at Hokkaido University's Fisheries School has contributed to the development of new techniques for placing reefs which reduce damage and permit controlled spacing of shelters. Spacing has been shown to influence turbulence effects. The influence of reef shapes has also been examined in efforts to design reef units that attract the more important commercial species.

Most of the larger reefs (*"jumbo gyosho"*) are designed to promote an upward current deflection, provide sheltered, darkened, calm areas, and allow for adequate circulation within the units. Many of the shelters are built from prefabricated components which are assembled at the shore staging area and transported by barges to the site. Some can be built in a variety of configurations from basic unit components.

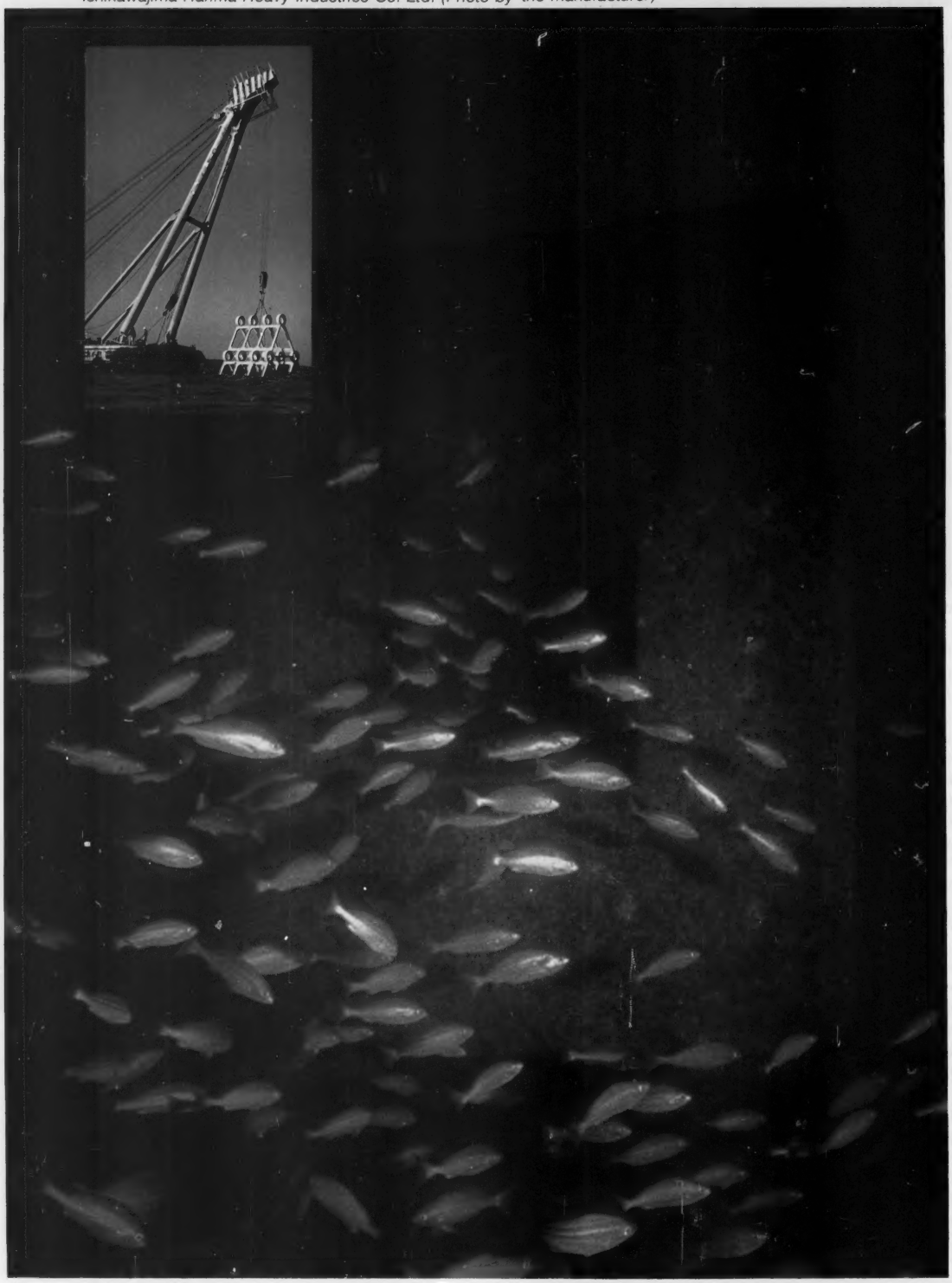
Fiberglass reinforced-plastic units are manufactured by Asahi Chemical International Ltd. in a variety of shapes and

*FRP fish shelter manufactured by Asahi Chemical International Ltd. (Photo courtesy of Dr. Ogawa)*



*Reinforced concrete "jumbo gyosho" manufactured by Onoda Cement Co. Ltd. (Photo by the manufacturer)*

*Reinforced concrete "jumbo gyosho" manufactured by Ishikawajima-Harima Heavy Industries Co. Ltd. (Photo by the manufacturer)*



"Jumbo gyosho" *in place. (Photo by the manufacturer)*

sizes. Twenty-three of these reefs have been constructed using units which range from 41 to 720 cubic meters each. These units have a large surface area which is rapidly colonized since there is no alkaline leaching. The reefs are generally weighted with concrete according to the site bottom type, wave conditions, and current velocity. The weight per unit area of these units is less than half that of concrete and they can be used in areas unsuitable for the more massive units. Installation is somewhat less expensive since the units can be towed to the installation site with the aid of air bag floats.

"Dragon Reefs" produced by the Onoda Cement Co. Ltd. have been placed at eight sites. The number of units per site ranges from 3 to 30; each unit weighs about 34mt and has a volume of 131 cubic meters. These units are made from eight reinforced concrete panels which are bolted and mortared together, and placed by a floating crane and barge. These shelters produce good current deflection in all orientations and influence both benthic and pelagic species. During the current year 150 additional units will be installed.

Reef units produced by Ishikawajima-Harima Heavy Industries Co. have been placed at 32 sites. Each site holds between 10 and 50 units, and each unit weighs about 22mt and has a volume of 139 cubic meters. These units are designed to generate an upward current which produces conditions conducive to fish congregation. The structure is built from reinforced concrete panels which are coupled together into triangular columns. They are installed using a floating crane.

## Improvement Programs for Specific Species

Most of the reefs designed for specific species are for invertebrates or seaweeds. Such small, shallow water reefs are known as "*tsukiiso*" in Japan. Over 40 percent of the current large-scale projects using this type of reef are for abalone, a very valuable species subjected to heavy fishing pressure.

A number of abalone hatcheries in Japan produce over a million juveniles (1.5 to 3.5cm) each year. Some of these hatcheries use warm water from electric power plants or geothermal sources to increase their production. The juveniles are generally sold to the fishermen who stock them in their fishing grounds.

Since hatchery-reared abalone can be distinguished from natural abalone by a shell color variation, fishermen and researchers can evaluate the effectiveness of the stocking programs. Return has been quite variable, ranging from almost zero to as high as 70 percent. One of the reasons postulated to account for this variation is the differences in the stocking habitats. Research indicates that stocking conditions in some areas could be greatly improved by altering the natural bottom with special shelter units.

A variety of special units are now being tested or are in use. Some are designed especially for juveniles; others for adults. Still other units are designed to improve conditions in natural nursery areas by limiting wave action, promoting food seaweed growth, or stabilizing the bottom. In some cases, special shelter units, designed to minimize predation or food competition, are directly stocked with juveniles.

## Tokushima Nursery Ground

Ecological studies in areas subjected to heavy storm wave conditions indicated that the wave action on inshore gravel and cobble is responsible for significant mortality in juvenile abalone in a natural nursery ground. The wave action also reduces the attached seaweed which provides the primary food for the growing abalone.

An effort to create an artificial nursery area has been undertaken by the Tokushima Prefectural Fisheries Experiment Station in cooperation with the local fishermen's association. It is funded, in part, by the national government. The project is designed to reduce wave action, promote seaweed growth, and stabilize near-shore gravel beds which are the habitat of newly settled abalone.

Based on biological, physical, and geological studies, a site near Abu City was chosen. Three types of concrete units were used to construct the nursery ground. At the seaward edge of the nursery, large hemispherical blocks weighing about 15mt where placed in two rows (1-2m deep) to break waves. Inside this area, truncated pyramid-shaped blocks with attached lines were placed to aid seaweed growth. In the near-shore (0.5m) zone, small jack units, with grooves to provide additional shelter for the juveniles, were set in the coarse gravel to stabilize the bottom.

Preliminary estimates are that survival and growth of naturally spawned abalone have been increased in the nursery area. Studies on predation rates and general ecology are now in progress.

## Fukushima-Taise Stocking Ground

In waters surrounding Hokkaido, the northernmost of Japan's major islands, several projects are aimed at integrating hatchery production with habitat improvement. These projects, conducted under the guidance of the Hokkaido Institute of Mariculture, are designed to increase the survival and growth of hatchery-stocked abalone by placing them in specially prepared shelter units.

*Abalone juveniles being stocked at Fukushima by Dr. Momma of the Hokkaido Institute of Mariculture.*

Special shelter units being stocked with abalone reared in geothermal hatchery, Taise, Hokkaido.

An adult abalone shelter unit with seaweed attachments on the Taise, Hokkaido stocking ground.

Abalone shelter units, for adults, are examined prior to placement.

In Fukushima, Hokkaido, 25 large concrete boxes (4mt each) with open sides are filled with natural rocks and placed in intertidal areas. The crevices formed by the rocks provide an excellent habitat for the juveniles which are stocked in PVC pipe sections. Special tidal channels designed to increase tidal flow have also been constructed as a part of this project. These units have been very successful and tagged seedlings have experienced improved survival and growth.

At Taise, Hokkaido, special juvenile stocking units—which are covered with plastic-coated wire to protect the seaweed food supply from sea urchins—are stocked with juvenile abalone. The abalone are raised to about 3cm at a local hatchery which uses geothermal heat to increase the growth rate of the abalone. The stocking is accomplished by divers who also monitor growth and survival. The stocking units are placed in near-shore waters 3 to 5 meters deep. Other units designed for the larger abalone are also located in this area. These units are fitted with special attachments to promote seaweed growth and thus provide both shelter and food for the abalone.

## Opportunities for Habitat Improvement in the U.S.

The U.S. currently faces both a growing domestic demand for seafood and a rapidly developing export market. Popular species such as lobster, shrimp, abalone, and scallops have become increasingly expensive and scarce in recent years. Imports now account for a substantial amount of the high-priced seafood consumed in this country. Now that foreign fleets are being gradually excluded from U.S. coastal waters by the 200-mile limit, opportunities for developing coastal fisheries are expanding rapidly. Habitat improvement technology offers a means for the U.S. to increase its commercial production of high-value species for both domestic consumption and overseas export.

Recreational fisheries as well could benefit from artificial reefs specifically designed and manufactured for optimum effect. Although sport fishermen—currently the major users of artificial reefs in the U.S.—do catch a substantial portion of the fish consumed in American homes, the most significant economic impact of sport fishing arises from the tourist dollars it generates. In communities near existing artificial reefs, increases in sport fishing have contributed measurably to the local economies.

Despite the use of "scrap" materials for most U.S. artificial reefs, by no means are these reefs built cost-free. Preparation is becoming increasingly expensive. EPA regulations require that wrecked cars must be thoroughly steam-cleaned to eliminate oil and other potential pollutants, and their upholstery must be removed. Old tires must be perforated to reduce buoyancy, bound together, compressed, ballasted with concrete, and transported to location. Because of their potential as a chemical energy source, tires often are no longer free or available at nominal charge. Still other materials that once were used for reefs are no longer available at all—old World War II Liberty ships, for example. And none of these materials offer the advantage of optimum design.

Specially designed and manufactured reefs do require a sizeable investment but it is a one-time, fixed-expense, and Americans can benefit from the extensive research and development already funded by the Japanese. If these reefs are properly engineered, sited, and placed, they represent a relatively permanent contribution to sport fisheries and commercial fisheries production. Additionally, they can be used in cost-effective combinations with other production methods. Hatcheries, for example, have the potential for increasing populations but require recurring expenditures subject to inflation; since artificial reefs significantly increase the survival and growth of stocked juveniles, they make hatchery expenditures more cost-effective.

As the Japanese have demonstrated, the habitat improvement techniques made possible by specially designed and manufactured artificial reefs have enormous potential for expanding coastal resources and rehabilitating areas adversely impacted by human activities such as pollution, construction, and overfishing. Similar artificial reefs could be used in the U.S. as a fisheries management tool with great potential benefits for commercial and recreational fisheries. ■

# Manatee: Endangered Marine Mammal

**by John R. Twiss, Jr.**

Beginning in the late 1960s the plight of marine mammal populations became a matter of increasingly widespread concern. The continued exploitation of depleted great whales for various commercial purposes, the killing of newborn harp seal pups for their fur, and the high porpoise mortality associated with the commercial yellowfin tuna fishery typify the problems which caused that concern.

From the Arctic to the Antarctic a sad story of over-exploitation of certain stocks of whales had been written. As one population became depleted and unprofitable to harvest, the whalers turned to other more numerous stocks to stay in business.

A telling account of the effects of harvesting on whales which feed in the Southern Ocean was given in 1976 by Richard M. Laws, Director of the British Antarctic Survey:

"Nearly thirty years ago, I first sailed from London to the Antarctic to work on the southern seals. One of the memorable sights was the large number of whales surrounding our small ship as we crawled across the vastness of the Southern Ocean. A few years later, I wintered at South Georgia and saw something of the whales and whaling operations there. A little later still . . . came my first close encounter with a living blue whale in the pack-ice—the others had mainly been dead on the flensing plan—and I experienced a great feeling of awe in the presence of the most magnificent of all animals . . . At the beginning of this year, I was again in the Antarctic and saw just a handful of large whales."

Growing recognition among scientists and the lay public of the plight of the whales worldwide was recently translated into action by the International Whaling Commission (IWC)—the intergovernmental body, including 23 member states, responsible for the regulation of whaling by its members. Beginning in 1974 with an effort to strengthen the basis for its regulations, the IWC has placed progressively heavier emphasis upon the advice of its scientific committee in setting quotas for whaling. At its meeting in July 1979, it banned factory-ship operations in all oceans and for all species except the minke whale. This decision will virtually eliminate Soviet commercial whaling in the North Pacific and will substantially reduce Soviet and Japanese whaling in the Southern Ocean. The IWC also set aside most of the Indian Ocean as a whale sanctuary for a period of ten years. These actions, coupled with prohibitions on the taking of certain species and reductions in the levels of take for other species, bespeak progress which may allow for the recovery of the great whales.

The 70s also saw progress toward

*Executive Director, Marine Mammal Commission, 1625 I Street, N.W., Washington, D.C., 20006 (Affiliation shown for identification only)*

*Manatees swimming in Blue Spring, Fla.*

reducing injury and death of porpoises incidental to the yellowfin tuna fishery. Certain species of porpoise associate with yellowfin tuna. When fishing, fishermen encircle porpoise schools in purse seine nets and thereby catch the yellowfin tuna which swim below the mammals. In the process, many porpoises drown or are otherwise killed or seriously injured. In 1972 about 300,000 porpoises were thus killed by U.S. vessels. Eventually, fishermen, environmentalists, scientists, and key Federal agency policy makers cooperatively addressed the issue. Although the problem is by no means solved, the estimated U.S. kill in 1978 was reduced to about 14,200 porpoises, less than one-twentieth of the 1972 estimate.

In trying to understand improved regulation of whaling, lowered porpoise kills, and other advances in wildlife protection, one often discovers common contributing factors such as strong public interest in the problem, effective statutory and regulatory mechanisms, and intensified theoretical and applied scientific efforts.

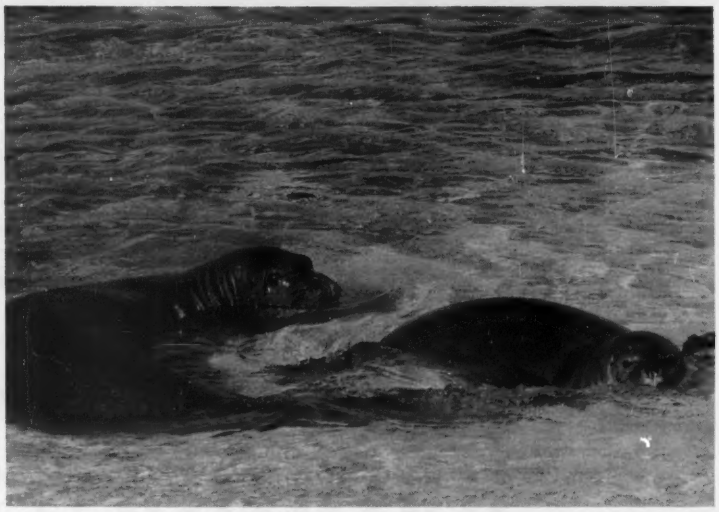
Public pressure has been effectively focused on a number of highly visible issues in which the adverse impacts have been clear. Such problems are those related to commercial whaling, massive numbers of marine mammals being killed or made to suffer, and flagrant habitat destruction.

Statutes, such as the Marine Mammal Protection Act of 1972 and the Endangered Species Act of 1973 (as amended in 1978), and regulations emanating from them have profoundly influenced many situations. This has been accomplished either by articulating specific statutory or regulatory goals applicable to a particular problem or species or by setting forth more general conservation goals which address biologically desirable population levels and the roles of animals as significant functioning elements of an ecosystem. Both Acts make possible litigation and administrative action to protect species and/or habitats.

Wildlife management theory has been evolving towards more ecosystem-oriented approaches. In speaking of living resource utilization, two leaders in the field, Sidney J. Holt and Lee M. Talbot, summarized the views of a large group of scientists as follows:

> The ecosystem should be **maintained in a desirable state such that: a) consumptive and non-consumptive values could be** maximized on a continuing basis, b) present and future options are insured, and c) risk of irreversible change or long-term adverse effects as a result of use is minimized.
>
> Management decisions should include a safety factor to allow for the fact that knowledge is limited and institutions are imperfect.
>
> Measures to conserve a wild living resource should be formulated and applied so as to avoid wasteful use of other resources.
>
> Survey or monitoring, analysis, and assessments should precede planned use and accompany actual use of wild living resources. The results should be made available promptly for critical public review.

While advances in law and science offer new protection for marine mammals and their habitats, much remains to be done. In some instances where the necessary statutory provisions exist to provide protection, but governmental action, public



*A Hawaiian Monk Seal mother and pup; the pup is near the age of weaning from the mother. (Photo by Kenyon)*

pressure, and/or research have been limited, progress has been disappointing. Witness the Hawaiian monk seal and the West Indian manatee.

Unlike the whaling and "tuna-porpoise" issues, there has been nothing particularly sensational or dramatic about the decline of the Hawaiian monk seal, a species found in limited numbers on certain of the Leeward Islands in the Hawaiian archipelago. It is an endangered species and may well be the only member of the genus *Monachus* with a chance of surviving the 20th century. The Caribbean monk seal *(Monachus tropicalis),* last seen in 1952, is probably extinct. The Mediterranean monk seal *(M. monachus),* which may be down to perhaps 500 animals, lives in areas subject to increasing pollution, ship traffic, and harassment. Thus the survival of the genus may depend upon the ability of the United States to protect the Hawaiian species.

The last actual count of Hawaiian monk seals was 653, and the total probably does not exceed 1000 animals. There have been sharp population declines on various of the islands in the last 20 years, the causes of which are not certain. Much research needs to be done to gain a better understanding of the causes of these declines. Intensive efforts must also address the seal's biology, distribution, migratory habits, and habitat needs. The monk seal's sensitivity to human intrusion has been recorded, and potential development of fisheries and other human activities in the Leeward Islands could pose a serious threat to the remaining animals.

In order to protect and encourage the recovery of this species, the National Marine Fisheries Service, the Federal agency responsible for monk seal protection, must successfully address a complex of issues involving intensive efforts to describe and carry out actions needed to save the animal, to assess the impacts of competitive uses contemplated for the islands and surrounding waters, and to resolve jurisdictional disputes over certain areas. The Service has begun the

*Although some animals are attracted to divers, many others become frightened away from their usual habitat.*

*Manatees often exhibit scars from previous encounters with boats. (Photo courtesy of National Fish & Wildlife Lab.)*

process, and proposals related to critical habitat designation and the development of a strategy to encourage the species' recovery are expected in the near future.

The West Indian manatee, like the monk seal, is among the most endangered of marine mammals inhabiting coastal waters of the United States. It is one of four living representatives of the ancient order *Sirenia*. The range and abundance of other sirenians—the dugong *(Dugong dugon)*, the West African manatee *(Trichechus senegalensis)*, and the Amazon manatee *(Trichechus inunguis)*—have shrunk dramatically in recent years. A fifth species, the Steller sea cow *(Hydrodamalis gigas)*, last seen in 1768, was exterminated by Russian fur seekers in the 18th century, less than 30 years after its discovery.

The West Indian manatee is a timid, gentle, herbivorous, slow-moving animal well adapted to foraging for aquatic plants and sea grasses with the help of its paddle-like forelimbs. It lacks hind limbs, has a horizontally flattened tail, is nearly hairless, and has a thick skin once highly prized for leather. Adults are 9 to 11½ feet long and may weigh up to a ton.

Firm data on reproduction are lacking. Calving seems to occur throughout the year, but no discrete calving areas have been identified. Cows usually bear a single calf, although what may have been twins have been seen. Newborn calves are about 3 feet long and weigh roughly 70 pounds. Nursing is believed to continue for up to two years, although suckling calves begin grazing within weeks of birth. Captive breeding of manatees has been recorded only twice. In 1975, a calf was born at the Miami Seaquarium of animals held captive together for 18 years and a second calf conceived in captivity was born in the Netherlands in 1977.

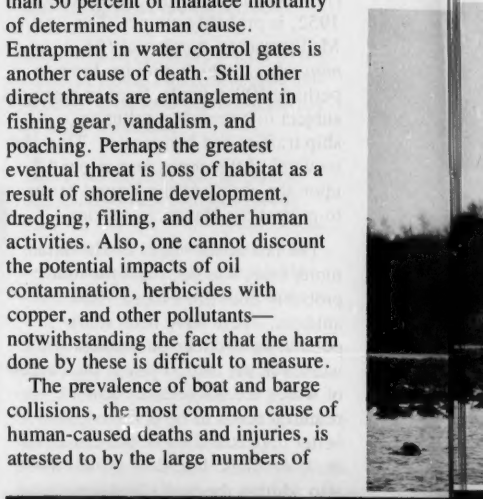
The manatee's summer range in the southeastern United States extends northward to the Carolinas on the Atlantic and to the northerly reaches of the Gulf Coast. Manatees are usually found in rivers, creeks, bayous, and canals during the warm summer months. With the onset of colder weather, they move to Florida waters where many appear to congregate near the roughly twenty warm water refugia, only six of which are natural warm water springs. The artificial ones are created by effluents from power plants and factories. A 1976 aerial survey of manatee distribution during a cold spell showed most manatees, except in the extreme southwest of Florida, to be within three miles of refugia. Although many animals may remain near a refuge for the entire winter, some move and the composition of the refugia populations changes.

If the West Indian manatee is not saved in American waters—in Florida and Puerto Rico—the species will have disappeared from a significant portion of its range. The Florida population is estimated at about 1000; the Puerto Rican population at 65 to 100 animals. Although it seems likely that the entire Virgin Islands population has been extirpated, a few manatees may still survive. The West Indian manatee also ranges in small numbers in the Bahamas, the Greater Antilles, and along the Caribbean and Atlantic coasts of Central and South America as far south as Recife, Brazil. Although no valid historical records on population distribution and abundance exist, it is known that manatees were taken in large numbers in the 16th through 19th centuries for meat, oil, hides, and other products.

Manatee mortality in Florida is high. Ninety-nine dead manatees were recovered in 1977 while 15 were confirmed dead but not recovered; in 1978, the respective figures were 78 and 6; and by July 30, 1979, 49 dead animals had been recovered and 4 more were verified dead but not recovered. If the population is as low as it seems and if the present rate of mortality continues, the Florida manatee will soon be gone.

To prevent this, death, injury, and disturbance of manatees caused by man *must* be reduced. Death or serious injury from collisions with boats and barges account for more than 50 percent of manatee mortality of determined human cause. Entrapment in water control gates is another cause of death. Still other direct threats are entanglement in fishing gear, vandalism, and poaching. Perhaps the greatest eventual threat is loss of habitat as a result of shoreline development, dredging, filling, and other human activities. Also, one cannot discount the potential impacts of oil contamination, herbicides with copper, and other pollutants—notwithstanding the fact that the harm done by these is difficult to measure.

The prevalence of boat and barge collisions, the most common cause of human-caused deaths and injuries, is attested to by the large numbers of



*A winter congregation of manatees near power plant discharge in Fla.; the warm water effluent is an attractant. (Photos by Pat Rose, Florida Audubon Society, unless otherwise noted.)*

*Manatee warning sign financed by the U.S. Fish & Wildlife Service. (Photo by Lynn Gilbert)*

*Four manatees are harassed by boats in the Orange River near Fort Myers, Fla. Note animals inside the wake.*

*An adult female with possible twins in Crystal River, Fla. (Photo by James A. Powell, Jr., National Fish & Wildlife Lab.)*

*Automatic flood control gate on the Miami River near Miami International Airport. In this downstream view, comb-like devices, partially out of the water, are designed to prevent manatees from going upstream through the dam. (Photo by John E. Reynolds)*

*This manatee was killed by a large boat propeller; the lung is protruding through the wound. (Photo by Daniel K. O'Dell, University of Miami)*

living manatees with propeller scars. Many non-fatal accidents have taken and are taking place. Manatees move slowly and are difficult to see, especially in turbid water. Not only are they vulnerable to fast moving boats but also to the large and slower moving vessels.

Automatic flood control structures are another important cause of manatee mortality—particularly in Dade County, Florida. Five dams have been implicated in manatee deaths. Although no one has actually seen a manatee become trapped, it is supposed that, as the flood-control gate opens, an animal feeding upstream from it may be pulled into the opening by the rush of water and pinned against the gate until it drowns. And quite possibly mothers, too large to pass through the opening, become trapped when they try to follow calves through the gate.

Fishing gear also causes manatee mortality and injury. Shrimp, hoop, and other fishing nets, trot lines, monofilament lines, and crab traps have all been implicated. Lines occasionally become so tightly wrapped around a manatee's flipper that circulation stops and gangrene results. Animals with hooks and lures embedded in their lips have been seen.

With respect to vandalism and poaching, biologist Daniel Hartman in 1971 put vandalism second only to boat and barge collisions as a cause of mortality. Animals bearing puncture wounds from bullets and sharp objects have been found. Carcasses of animals butchered for meat are not unknown.

Habitat loss is a serious problem affecting the manatee. In the King's Bay area of Florida's Crystal River, declared in 1976 to be Critical Habitat for manatees, several islands are being considered for development. One island adjoins the spring which serves as the largest natural warm water winter refuge for manatees, and there is little doubt that manatees could be seriously affected by additional boat and diver traffic, possible loss of aquatic vegetation, and other human-induced changes.

Although the foregoing threats to manatee survival are generally recognized, much remains to be done to address them. Increased public awareness and education is, without question, critical. Public interest in manatees, although growing, has never been as intense as in seals, whales, dolphins, and other marine mammals of wider distribution. The sad fact is that there is nothing sensational about manatee depletion which captures public attention. Populations are being whittled away by single incidents which excite little interest though their cumulative effect is devastating.

Who can help the West Indian manatee? Federal and state agencies, conservation and animal-welfare

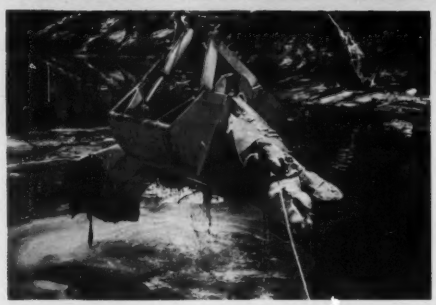
groups, aquariums, educational institutions, and private industries have all been involved in recent research, education, and regulatory efforts. Their continued and increased participation is absolutely essential to the success of any future efforts to protect and encourage the recovery of this species.

A master plan is needed to develop and implement cooperative management, research, education, and enforcement actions with respect to the manatee. Part of the solution lies in the Endangered Species Act which requires the Secretary of the Interior to develop and implement recovery plans for the conservation and survival of endangered and threatened species. The Act's legislative history discusses the importance of recovery teams in developing recovery plans and notes that plans, periodically reviewed and updated, should provide a framework for specific actions directed toward conserving the species.

The Fish and Wildlife Service, the Federal agency with lead responsibility for the manatee under the Endangered Species and Marine Mammal Protection Acts, is now developing a recovery plan. When completed, the plan should call for research on the biology and life history of the animal as well as for research directly applicable to addressing identified threats. It should also set forth improved management strategies and practices which: are vigorously supportive of policies and provisions of the Marine Mammal Protection Act, the Endangered Species Act, and the Florida Manatee Sanctuary Act; provide for designation of new areas of biological significance in need of special protection; and allow for the development and implementation of new protective regulations. Among the points that such a plan should cover are specific commitments to monitor populations, to minimize harassment, to minimize human-caused injuries and mortalities, to protect habitats, and to better understand the biology and life history of the animals. If the plan is completed with benefit of the constructive contributions of all interested parties, it should meet these objectives and much will have been accomplished.

Although recognition of the urgency of taking strong remedial action to protect and encourage the recovery of this species was too long delayed, a turning point may have been reached. What is needed, now and when the plan is completed, is action to translate shared concerns and commitments into actual realized benefits to this endangered species before it is too late. ■

*A manatee that has died from blood poisoning; ropes tied to the flippers by vandals caused a cut-off of circulation. (Photo courtesy of Sea World of Florida)*



*A dead manatee is recovered in a clam-shell bucket. (Photo by Reynolds)*

# Building American Canals

## Part 1-The Federal Period

**by Paul K. Walker**

*The Chesapeake and Ohio Canal, where it transits Georgetown, Washington, D.C. (CofE Photo)*

In late October 1825, from Buffalo to New York City, grand celebrations—marked by parades, balls, parties, theatrical performances, banquets, and fireworks—heralded completion of America's supreme achievement in canal building, the Erie Canal. America's great canal era had come of age. Although lesser canals were not new to America—by 1815 canals spanning nearly one hundred miles notched the landscape from New Hampshire to South Carolina—their combined mileage was less than one third that of the Erie. These early artificial waterways played an important role in the overall development of America's transportation network.

Several decades before the end of the Eighteenth Century, events in England spurred American thinking on the economic importance of canals. A boom in canal construction began there before the American Revolution. In 1760, Francis Egerton, the third duke of Bridgewater, completed the first English canal built totally independent of a stream. The success of Bridgewater's Canal, linking his coal mines with industrial Manchester, inspired imitations. In 1769 the American Philosophical Society, which followed scientific developments closely, agreed to help a group of local Philadelphia merchants by supplying personnel and equipment for surveys to determine the feasibility of a canal linking the Chesapeake Bay with the Delaware River.

But George Washington was the most significant factor behind early transportation improvements in America. As a surveyor, military officer, and landholder, he had a long association with the wilderness lands west of the Appalachians, the 300-mile wide, 1300-mile long natural barrier to internal development running from the Green Mountains of Vermont to northern Alabama.

The vitality of the western region deeply impressed him. Washington wanted to "open

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all communications which nature has afforded, between the Atlantic States and the Western Territory, and to encourage the use of them to the utmost." In his view the Appalachians could be surmounted if existing waterways were improved and the necessary man-made connections forged between them.

Several journeys Washington made over the mountains in the early 1770s inspired him to push for improved Potomac River navigation, combined with a land passage to the headwaters of the Ohio, as the preferred means of shaping an east-west link. He won Virginia's approval for a private company to open Potomac navigation 150 miles upriver from the tidewater, but the Maryland legislature balked. Although war then intervened, Washington kept this vision alive.

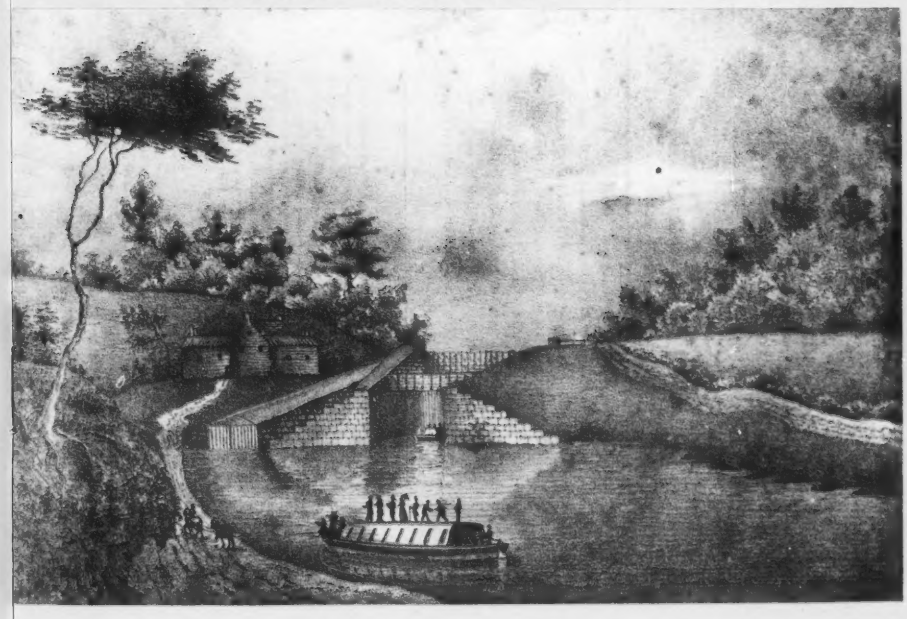
At Mount Vernon in the mid-1780s, Washington frequently turned after-dinner conversation to the subject of improving America's inland navigation. No matter that his guests expected, and generally preferred, to hear their host relate exciting first-hand accounts of Revolutionary War battles. The retired commander-in-chief of the Continental Army was determined to instill his views in others. America's new status as an independent nation added a sense of urgency and excitement to his endeavor.

To one influential Virginian, Washington maintained that internal trade was crucial in order to strengthen the "ties of consanguinity which are weakening every day" and that "commercial connexsions, it is well known, lead to others, and united, are difficult to be broken." To James Madison he wrote: "Let us in all matters of general concern act as a nation, which have national objects to promote, and a national character to support." Internal improvements, Washington asserted, attractively combined public spirit with private gain. Rising to the challenge was "a duty incumbent both on governments and individual citizens." He found, however, that convincing others was no easy task.

Fortunately Governor Benjamin Harrison of Virginia found merit in the Potomac proposal and ordered Washington to make a detailed survey. In September 1784 the general began a horseback and foot journey that carried him more than 600 miles to the headwaters of the Ohio and back. All about him he observed a region bursting with energy and rich in potential.

At the end of his expedition Washington submitted a report to Harrison in which he frankly compared the Potomac route with one extending from the St. Lawrence or from the Hudson. Downplaying his personal interest in a successful Potomac scheme, Washington stated the matter simply: the headwaters of the Potomac were more than 150 miles closer to Detroit than either those of the St. Lawrence or the Hudson. Washington acknowledged that New York and Pennsylvania would eventually develop their own routes. He even welcomed the competition. But the time was ripe for Virginia to act.

Washington's deft arguments overcame Maryland's earlier objections. In response to pressure from the southern part of the state,



*The junction of the Northern and Western Canals. (From Colden's Memoirs)*

Virginia added a companion measure calling for improvement of the James River. Thus two companies—the Potomac Company and the James River Company—were born. Washington invested heavily in each enterprise and served them both as president, but remained most loyal to his pet project on the Potomac.

The immediate goal of the Potomac Company was to circumvent the river's worst obstructions from Great Falls southward with a series of short canals, and to open the remainder of the river to free navigation by clearing the channel. Great Falls, outside Washington, D.C., presented the thorniest engineering challenge. Construction began there in the summer of 1786.

As the Potomac Company quickly discovered, engineers were rarely to be found, and of those who were available, few had ever seen a canal operate or understood how locks worked. The acute shortage of trained, native engineers directly resulted from the lack of formal schools, both military and civilian, in America. As commander-in-chief Washington had experienced first-hand the frustration and embarrassment of having too few trained engineers and of having to enlist foreigners. During the war he tried unsuccessfully to create a military academy whose function would be to train officers in technical subjects, including engineering. In peacetime, without an academy and with the Corps of Engineers mustered out of service, the situation became no better.

Washington, as the canal company president, again turned abroad for assistance. In 1786 he wrote Lafayette, his good friend in France, seeking recommendations. The appeal was unsuccessful. So for a short time at the outset the Potomac Company employed as its canal construction manager James Rumsey, the inventor of a mechanical boat whose ideas had impressed Washington. When the arrangement did not work out, Rumsey resigned. One of the company's directors then took charge, a common practice on early canal projects. Finally in 1796 the company was able to hire Christopher Meyers, one of several experienced British engineers who came to America seeking work. William Weston, a pupil of James Brindley, builder of Bridgewater's Canal, was also briefly employed.

The changes in engineers, combined with high costs and waning stockholder interest, delayed completion of the five locks at Great Falls until 1802, three years after Washington's death. Four additional canals were built below Great Falls. The works at Little Falls were the longest at 3814 feet. By 1790 the James River Company completed its navigation improvements and a canal bypassing the rapids from Richmond to Westham, a distance of seven miles. Both endeavors fell short of the expansive scheme first envisioned by Washington. In fact the original Potomac venture collapsed entirely in the 1820s, later to be replaced by the Chesapeake and Ohio Canal Company.

*An Erie Canal boat negotiates the lock at Lockport, N.Y. in 1825. (From Colden's* Memoirs)

Although it was a far less grand scheme than that involving the Potomac, a project to link northeastern North Carolina with Virginia's ports on the Chesapeake Bay had also stirred Washington's imagination, and his support led to the formation of the great Dismal Swamp Company in 1787. In combination with improvements elsewhere in the state, he maintained, it would "open channels of convenience and wealth to the citizens of this State that the imagination can hardly extend to and render this the most favored Country in the Universe." Again he conducted a personal survey of the area, and decided to invest $500 of his own money. James Madison, Patrick Henry, George Mason, and other prominent Virginians followed Washington's lead, and the first section of the canal opened in 1794. Before long flat boats carried cargoes of juniper shingles out of the swamp at a cost far lower than had been possible using roads constructed especially for that purpose. The Great Dismal Canal was one of the most successful canals of the pre-Erie Canal period.

Partly in response to the Virginia ventures, a flurry of canal building activity also appeared in Pennsylvania, New York, Massachusetts, South Carolina, and Ohio before 1800. To a varying degree promoters of these projects experienced similar difficulties in finding engineers. Whenever men possessing even a few of the requisite skills were available, they were in great demand.

Financial woes repeatedly plagued the early canal endeavors. Unlike roads, canals required a substantial initial investment. Private capital was in short supply. Furthermore, corporate enterprise, through which investments could have been channeled, was in its infancy. State governments often subscribed a portion of the stock—Maryland and Virginia were pioneers in this regard—or authorized lotteries to raise money. But such funds were still insufficient at a time when estimates often fell far short of the final cost.

In Pennsylvania canal enthusiasts sought to improve navigation on the lower Susquehanna and open a passage from the Chesapeake Bay to the Delaware, the idea supported earlier by the American Philosophical Society. A canal connecting the Delaware and Schuylkill rivers was a second goal. In both instances promoters looked toward the economic benefits from improved communication between Philadelphia and the Pennsylvania backcountry.

Initial efforts to involve Maryland and Delaware in the Chesapeake Bay — Delaware River venture failed. Baltimore businessmen feared the impact of diverting trade to their rival port city, Philadelphia. Finally in 1803,

*Canvass White (1790-1834) was one of the nation's earliest canal engineers, and was largely responsible for the success of the Erie, and the Louisville and Portland Canals. (From Stuart's* Lives And Works Of Civil And Military Engineers Of America *(1871))*

*Albert Gallatin, Secretary of the Treasury under Presidents Jefferson and Madison, was an early supporter of canal building. (Courtesy of National Archives)*

after more than a decade of lobbying by the Pennsylvania Society for Promoting the Improvement of Roads and Inland Navigation, the three states approved a charter organizing the Chesapeake and Delaware Canal Company. Over a two-year period, Benjamin Henry Latrobe, a noted architect and civil engineer, completed final surveys of the canal route and started construction on a feeder. Money soon ran out. The majority of the company's stockholders balked at the high cost — nearly $100,000 spent and very little to show for it — and continuing assessments. An appeal for Federal help fell on deaf ears. As a result the company ceased operations until the Erie Canal craze spurred a revival in 1825.

Pennsylvania's second canal venture was only a little more successful. Between 1792 and 1795 the Schuylkill and Susquehanna and the Delaware and Susquehanna companies dug a canal fifteen miles long; but financial hardship delayed further progress. The state authorized the companies to raise $400,000 by lottery, but after 15 years they had brought in only $60,000. Neither a merger to form the Union Canal Company in 1811, nor an extension of the lottery provision and a state offer to subscribe $300,000 in stock helped. Only word of plans to build a major canal in New York overcame investors' lethargy. Awakened Philadelphians took over the Schuylkill portion of the Union project in 1815.

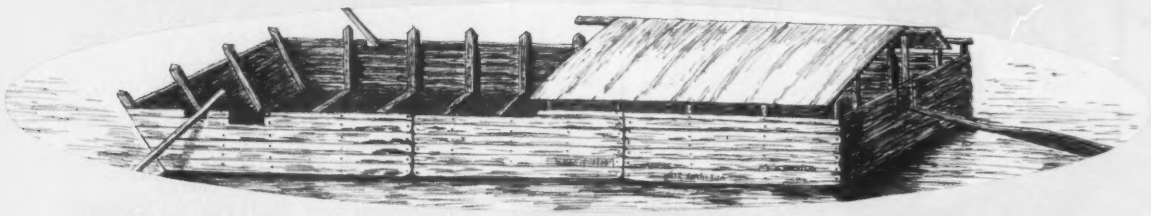
In New York, like Virginia, early canal development owed much to a single individual, Elkanah Watson, a merchant apprentice in the prestigious firm of Brown and Sons in Providence, Rhode Island. As a diplomatic courier during the Revolution, Watson traveled to Europe. In Holland he made an intensive study of canals and was impressed by what he saw. But a visit to Washington at Mount Vernon in 1785 was decisive. As Watson later recalled, it "ignited a canal flame in my mind."

Travels made in western New York and in the South before settling down in Albany in 1791, turned the flame white hot. Watson compiled a report of his journeys and used it to win crucial support from General Philip Schuyler and Governor George Clinton. The following year his efforts paid off. The state legislature approved two ventures to open canal navigation between the Hudson and Lakes Ontario and Champlain. By late 1795 builders had canaled a passage around the Little Falls on the Mohawk River by blasting their way through solid rock. This short improvement—it was less than one mile long—had an immediate impact on the state. The cost of shipping goods from Schenectady to Seneca Lake plunged. Anticipating future growth, settlers began a steady movement into the central and western portions of the state. Here was convincing evidence to support Watson's arguments favoring a system of canals and river improvements that would open a passage all the way to Lake Erie.

The experience on the Hudson-Champlain route in New York offered a sharp contrast. A great deal of money was spent, but virtually nothing was accomplished. Experiences like this one, coupled with the sheer boldness of a cross-state venture, severely undercut the proponents of the Erie Canal. What company, potential investors asked, could hope to build a canal more than 350 miles long when much smaller enterprises had failed?

*Lock No. 6 on the Chesapeake and Ohio Canal near the District of Columbia. (CofE Photo)*

In Massachusetts, Superior Court Judge James Sullivan championed a canal connecting Boston harbor with the Merrimac River, the major outlet for New Hampshire's valuable timber supply. Construction began in September 1794, under the direction of William Weston, a British engineer who also worked on canals in New York, Pennsylvania, and Virginia. Weston's Middlesex Canal, spanning 27 miles and boasting 20 locks, nearly 50 bridges, and 8 aqueducts—the longest of which was 280 feet—opened to boat traffic in 1803. Unlike most of the early canals, the Middlesex ran entirely clear of existing navigable waterways.



*A sketch of a flat bottom boat such as were used to descend the Ohio and Mississippi. (From* A Journey In North America in 1796 *by Collot)*

To its credit the Middlesex Company completed the project it set out to build, but the company experienced considerable difficulty meeting expenses when actual costs far exceeded preliminary estimates. Over a 20-year period the company had to assess its stockholders nearly one hundred times. Assessments finally exceeded dividends by close to $200 per share! Little wonder that with such negative returns investors were hard to find.

In South Carolina, between 1793 and 1800, advocates of improved trade between Charleston and the interior farmland built the Santee Canal, a 22-mile waterway connecting the Cooper and Santee Rivers. Swedish-born Colonel John Christian Senf, South Carolina's state engineer, was a man of strong convictions that frequently inhibited his ability to get along with others. But the Santee Company was fortunate that Senf was readily available, and they hired him to dig their canal. When completed the Santee boasted 13 brick and stone locks. Aqueducts conveyed streams under the canal and bridges carried roads over the waterway. A bridge crossed the canal at each lock. Even though large river boats were unable to pass through the Santee, the canal did a brisk business from smaller boats. They carried cotton through the canal at a cost less than half the charge to carry it by land.

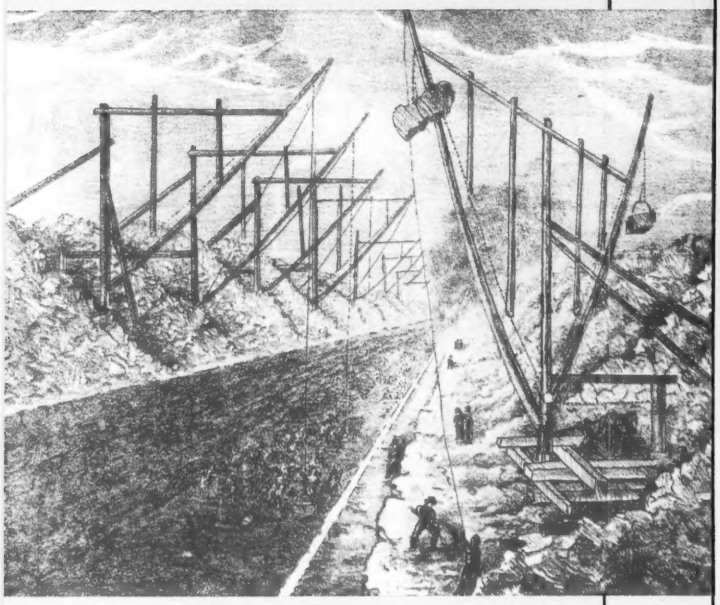
At the falls of the Ohio River below Louisville, risky passage forced shippers to land and pay for portage. As early as the 1780s, Captain Gilbert Imlay, deputy surveyor of Kentucky, first suggested building a canal to eliminate the overland trek. A survey was not made until two decades later, but, at the time, Colonel Jonathan Williams, who was soon to become chief engineer and superintendent of the Military Academy, concluded that "it would be easy to make a canal (here)." What seemed a logical solution to the problem was not readily achieved. Strongly motivated by self-interest, canal supporters divided into two rival groups, one from Kentucky and the other from Ohio. Each group favored a location at Louisville on opposite sides of the river. Their often petty disagreements helped delay any real progress until after the War of 1812. Yet the importance of improved transportation to the region had been established. Like the Potomac, Chesapeake and Delaware, Union, and New York State canal enterprises, this one on the Ohio became the basis for further development after completion of the Erie.

America's early canal-building endeavors occurred at a time when debate raged over what role the Constitution permitted the Federal government to play in economic development. The financial difficulties experienced by the canal companies soon convinced them of the necessity for Federal assistance. Pressure built up increasingly on Congress and the President to intervene, but the response was never satisfying.

In 1805, champions of the Chesapeake and Delaware Canal launched a major lobbying effort with a petition for aid to the Pennsylvania government and to Congress. It seemed proper, they argued, to focus on Congress for works "whose advantages are of general importance to the Union." The Pennsylvanians maintained that "a public work of such magnitude and importance, and of a kind nearly new in the United States, requires not only more extensive funds, but a greater portion of fortitude and perseverance than the individuals who are embarked in it can be supposed to possess." They advanced three basic arguments to bolster their case: canals had already had an immense impact in England; canals would enable the fulfillment of America's promise; and "the difficult and tedious communication" during the

Revolutionary War had been "injurious to our defence" and had "assisted our enemies."

Thomas Jefferson generally opposed the exercise of Federal power, but when it came to westward expansion his Constitutional scruples gave way. Thus, when Congress passed a resolution in February 1807 calling on him to



*Erie Canal excavations near the present site of Lockport, N.Y. in 1825. (From Colden's* Memoirs Of The Opening Of The Erie Canal *(1825))*

authorize a plan for a general system of internal improvements, he responded readily and directed Albert Gallatin, the Secretary of the Treasury, to examine existing projects, determine past mistakes and future needs, and recommend a course of action. Gallatin sent questionnaires to each canal company and spent a year collecting and sifting through their responses. His *Report on Roads and Canals,* containing the first coherent plan for internal development spearheaded by the Federal government, finally reached the Senate floor on April 6, 1808.

Gallatin argued that haphazard, uncoordinated local developments would never realize their potential unless they were integrated into a well-planned system designed by the Federal government. The active canal companies cited scarce capital and lack of engineers as the most serious handicaps to success. Gallatin made no suggestions about solving the engineering problem, but he did advocate government expenditures. Even though more and more capital was becoming available in certain areas of the country, he pointed out that the low-yield canal ventures were not attracting investors. Gallatin estimated that $16 million would be needed to implement his program to improve south and east-west communications by means of roads and canals.

The Gallatin plan came at an unfortunate time to win Congressional approval. Worsening relations with Britain were severely curtailing trade while the Treasury surpluses intended to pay for the program were steadily dwindling. States' Righters in Congress—and their voice was a strong one—objected that Gallatin's program would benefit only a select few areas, and that its constitutionality was dubious. Beginning in 1812, war effectively shut off all discussion of the issue for the next three years.

Ultimately, however, the War of 1812 underscored the value of internal improvements more clearly than any arguments yet advanced in their favor. Transporting troops and supplies proved almost as difficult as it had been during the Revolution. The existing road network—a conglomeration of turnpikes, military roads, and trails that were seasonably impassable—seemed no match for the potential speed and economy of canals. An enemy embargo of shipping again pointed out the danger of relying on coastal waterways. These factors, combined with the pressure exerted by an expanding western population and the search for new markets, generated substantial support for the development of internal transportation on a broad scale.

The Federal government rejected a leadership role. Fortunately the states accepted the challenge.

The Erie Canal proved a turning point. It succeeded where others had failed, and it did so on a grand scale. Built with private and state funds, the Erie reduced shipping costs so substantially that investors—both foreign and domestic—scrambled to reap the dividends. Scores of rivals followed in the Erie's path.

In addition to building investor confidence and demonstrating that canals could have a sizable economic impact, the Erie began to alleviate the engineer shortage. First-hand experience proved as excellent a teacher on the Erie as it had earlier elsewhere, only in this case the engineering problems surpassed any presented before. The canal spanned more than three times as many miles as all of the existing canals combined. Its course ran entirely independent of natural waterways and crossed a region that was largely uncleared and unsettled.

As a training ground for civil engineers, the Erie Canal produced a number of highly

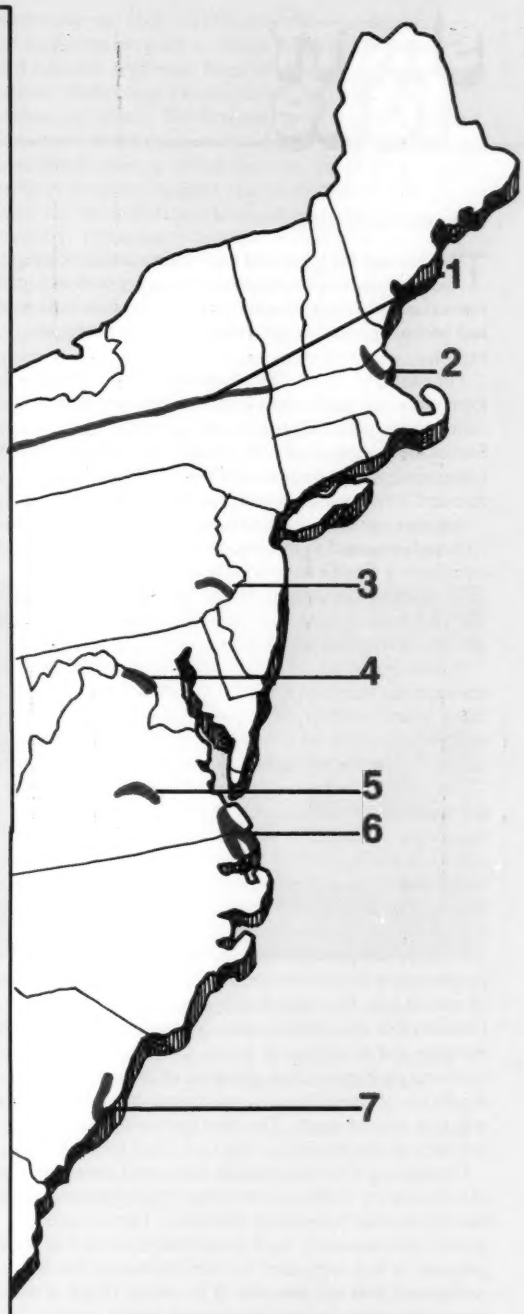
respected men who later moved on to direct a wide variety of civil works projects. An outstanding example was Canvass White, a frail young man without engineering training or experience when he joined the Erie Canal as an assistant surveyor in 1816. White established his reputation through a combination of inborn talent, knowledge gained from observations of British canal-building techniques, and practical experience on the Erie Canal. While working on the Erie, White developed and patented a new type of waterproof cement made from local limestone previously thought unusable. After leaving the Erie project, White served as chief canal engineer for companies in Pennsylvania, Connecticut and New Jersey. John B. Jervis, another product of the Erie, progressed from axeman to rodman, to construction engineer for a portion of the canal, and finally chief engineer. Before the canal was completed, several other companies tried to hire him away.

After 1815, the Army, boasting a revitalized Corps of Engineers and a firmly established military academy, also played a part in reducing the chronic engineer shortage. In the future Engineer officers would increasingly put their surveying and construction skills to work carrying out a program of internal development that included river improvements and canals. While the training received at West Point added a new dimension to the engineer's skills, a strong commitment emerged to supplement training with experience. The Army viewed experience on civil projects as a useful adjunct to the defense-related work of its engineers. Washington—the military man, the Virginian whose vision of civil improvements transcended allegiance to his own state—would no doubt have been extremely proud of these developments.

Ironically, the Erie Canal, which had overshadowed and surpassed earlier canal-building efforts, was itself soon outdistanced. Simultaneous events on July 4,1828, provided a clue to the future.

On that day President John Q. Adams turned a spade of earth to initiate the second phase of Potomac River canal improvements. A few miles away near Baltimore, Charles Carroll of Carrollton, a signer of the Declaration of Independence, laid the cornerstone for another transportation advancement. Only Carroll's act made way not for a great ditch but for iron rails! ■

**The concluding installment of this look at the history of American canal building, covering the period from the 1830s to the present day, will be featured in an upcoming issue of *Water Spectrum*.**




*Green markings show the approximate locations of canals extant in the United States by 1825.*
*#1—Erie Canal; #2—Middlesex; #3—Schuylkill and Susquehanna; #4—Potomac; #5—James River; #6—Great Dismal Swamp; #7—Santee.*

short take

# Geopressure: AN ENERGY ALTERNATIVE

**by Keith Westhusing**

The demand for increased exploration and development of sources for the nation's energy pool has ignited interest in "unconventional" gas reserves that until now had been dismissed as too difficult and too costly to exploit.

For example, the Rocky Mountains contain large formations of "tight sands" gas which are estimated to contain more than 600 trillion cubic feet (Tcf) of gas. Stimulation, using hydraulic fracturing, has been tried with some success, but no generally successful pattern of resource location and stimulation has emerged.

Another source is the methane contained in coal beds. Although a hazard to mining, this "coal seam" gas represents a significant potential resource of natural gas—estimated at more than 300 Tcf for total gas in place. The problems include locating areas of gas concentration and recovering it economically.

A third possibility is Devonian shale gas. Although this resource has been tapped in the Appalachian region for many years, much of the in-place resource of over 500 Tcf requires new retrieval technology. Explosive stimulation and hydraulic fracturing have been only partly successful.

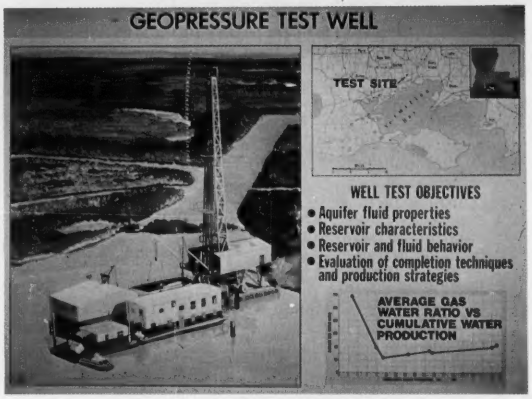
Yet another source are gas hydrates—frozen methane and water in an icelike substance thought to exist in significant quantities in the colder regions of the world's oceans and in permafrost areas. The size of the resource is highly uncertain and most of the studies have been done in Russia. The potential from areas near the U.S. coasts or Alaska has not been established.

Finally, and perhaps the most promising, are the geopressured formations containing substantial quantities of natural gas, fluid heat and hydraulic energy. Considerable uncertainty exists concerning the size of the resource and development awaits solution of significant technical problems. Demonstration of the commercial feasibility of producing gas and energy from these zones will take several years. The most promising area for research of this resource is the U.S. Gulf Coast Basin.

Geopressured (or abnormally pressured) zones are areas of sedimentary deposits containing trapped water at higher than the normal hydrostatic pressures. These trapped waters have unusually high temperatures as well as high pressure. It was suggested in 1966 (Hottman) that the geothermal heat and pressure of the saline fluids of these formations might be used for process heat or power generation and that the methane entrained in the fluids could be produced as a third energy source.

Some of the deep wells drilled in the Gulf Coast that penetrated geopressured formations have detected abnormal pressures indicated by gas "kicks" and flow of saline water. Some of these resulted in hazardous and expensive blow-outs that required considerable effort to contain and control. The deep sediments are usually undercompacted below depths of from 6000 to 10,000 feet and contain saline fluids which carry part of the overburden load. The abnormally high pressures encountered are believed to originate as sedimentary deposits are overlain by new deposits and become deeply buried.

The fluids contained in the deeper formation are pressed out by the pressure of the overburden, and the thickness


GEOPRESSURE TEST WELL
TEST SITE
WELL TEST OBJECTIVES
• Aquifer fluid properties
• Reservoir characteristics
• Reservoir and fluid behavior
• Evaluation of completion techniques and production strategies
AVERAGE GAS WATER RATIO VS CUMULATIVE WATER PRODUCTION

and porosity of these deeper sediments decreases. The rate of water expulsion is controlled by the permeability of overlying rocks. If none of the water can escape, a portion of the weight of the overburden is borne by the fluids contained in the lower sediments. The result is a dramatic increase in formation fluid pressure. Fluid pressure gradients in the geopressured regions often approach the pressure exerted by the overlying rocks themselves.

The fluids contained within these regions will flow naturally into wellbores and then to the surface where the heat energy and hydraulic energy may be converted to useful purposes such as electricity generation. The fluids in these zones have become hotter than normally pressured formation fluids because the upward migration, and some of the normal heat flow rate to the surface, has been impeded by the overlying insulating layers of impermeable shales and clays. Temperature gradients in geopressured zones are generally greater than the rate encountered in normally pressured zones. Temperatures as high as 350°F have been measured at 15,000 feet in geopressured zones.

*Mr. Westhusing is with the Department of Energy in Houston, Texas.*

Evidence of methane concentration in geopressured zones is based on inflows of gas and water, from blowouts, and from the large number of kicks encountered when drilling into geopressured sandstones. Gas measuring devices on mud logging units also often record significant indications of gas saturation while drilling is in progress. Estimates of the gas content in geopressured aquifers are extrapolated from measurements of normally pressured formation fluids. These were almost all saturated with gas. Analysis of a very limited number of geopressured zones indicates that this may also hold for geopressured waters.

A U.S. Geological Survey study (Papadopulos and others) in 1975 assessed the resource potential of the geopressured-geothermal reservoirs contained within the onshore portion of the Tertiary sediments. The study covered an area of about 56,000 square miles along the Gulf Coast between the top of the geopressured zones and the maximum depth of well control (20,000 feet in Texas and 23,000 feet in Louisiana). Geopressured fluids were rated for the thermal energy of hot water, the hydraulic energy of the water under pressure, and the chemical energy of the methane. The energy resource base was estimated at 43,331 quads for thermal, 198 quads for hydraulic or mechanical energy and 23,927 quads for the gas (1 Quad = 1 Tcf of gas).

Others that have examined prospect areas in Texas and Louisiana in detail provide differing estimates for the geopressured energy resource base and recoverable energy. The disparity in resource base estimates and the recoverable energy is indicative of the limited amount of firm resource data available and underscores the need for acquiring such data through well testing of geopressured-geothermal saline aquifers. Even the lower recoverable geopressured gas estimates are significant and, if the moderate temperature water can be used as an effective energy source, the geopressured-geothermal resource can contribute meaningfully to alleviating the U.S. energy shortage. Accordingly, the Department of Energy has embarked on a program to determine the feasibility of developing this potentially significant resource.

Budgetary allocations provided by DOE for geopressured-geothermal resource development have increased from $1.1 million in FY 1975 to an anticipated $36 million per year in FY 1980. A major portion of the funding in the later years has been directed toward higher resolution studies of reservoir areas and actual geopressured reservoir testing in existing oil and gas wells, or through the drilling, completing and testing of specially designed wells which are capable of producing 40,000 barrels of geopressured fluid per day. Such testing will evaluate the potential for methane recovery and lead to the design of experimental and demonstration facilities for direct heat applications and electricity generating facilities. The program schedule to 1984 indicates the near-term emphasis is on gaining resource information through well testing in promising prospect areas.

The DOE program is designed to provide data on the size of the potential resource; the feasibility and type of reservoir development; the economics of resource production (both for methane and thermal recovery); and, the magnitude and cost of environmental considerations.

The long-term program to obtain this information is divided into five segments: Regional Planning; Resource Definition; Technology Development; Facilities; and, Environmental Issues. The first four areas require detailed examination beyond the purview of this article. In the environmental arena, a topical concern, the DOE geopressure program includes studies to determine if potential environmental problems can be handled successfully. The areas of concern include land subsidence, water disposal, and thermal pollution.

The environmental study is composed of two parts: programs associated with specific geopressured resource development sites (e.g. Brazoria County, Texas) and programs to resolve generalized resource development problems.

Specific resource development sites require regional environmental baseline studies to determine the present state of the environment; data collection and analyses associated with selecting well sites within prospect areas where development would have the minimum environmental impact; analyses to thoroughly examine the impact at specific sites; and, monitoring to measure the effects of drilling, producing and disposing of large volumes of geopressured -geothermal fluids.

General geopressured resource development concerns include research into the potential for subsidence and subsidence measurement techniques; studies related to the seismicity that may be induced along growth faults owing to large volume fluid withdrawal, and determination of methods for economical and environmentally acceptable waste fluid withdrawal. ■

*The rolling character of the Piedmont Upland Section is best exemplified by the broad and powerful waters of Virginia's James River. (Photos by the author.)*

# Wild River INVENTORY

**by J. Glenn Eugster**

The National Wild and Scenic Rivers System (NWSRS) is part of a Federal program of recognition and protection of the rich concentration of natural ecosystems, scenic beauty, and historic and recreational values in our nation's river corridors. In his 1979 message on the environment, President Carter expressed concern that development along the banks of rivers continues to outpace our ability to protect those rivers which might qualify for inclusion in the NWSRS. This problem is particularly acute near urban areas, where there are greater demands for recreational opportunities which can partly be met by river protection. As an alternative to the protection offered by the NWSRS, many state and local governments have begun to take initiative in protecting rivers. In the northeast, where there are many densely populated urban areas and comparatively few rivers which are free of development, the results of a recent Federal survey demonstrate that there is a great diversity of rivers and river segments which are worthy of protection.

The Department of Interior's Heritage Conservation and Recreation Service (HCRS) has completed a 13-state, Maine to Virginia, inventory of the northeastern United States to identify those rivers potentially suitable for inclusion in the NWSRS. More than 5300 miles, along 171 rivers and river segments, were identified.

The Inventory, begun in 1975, was prepared in response to a mandate of the National Wild and Scenic Rivers Act *(P.L. 90-542)*, which authorizes the Secretaries of Interior and Agriculture to "make specific studies and investigations to determine which additional wild, scenic and recreation river areas within the United States shall be evaluated in planning reports by all Federal agencies as potential alternative uses of water and related land resources involved."

The objective of the River Inventory has been to identify and evaluate those rivers or stream segments, generally 25 miles or more in length (there are numerous exceptions), and in a relatively natural condition, which might merit some type of protective, conservation or preservation measures.

The Northeast Office of the HCRS is one of seven regional offices which are participating in the rivers' inventory. Along with the Northeast study, similar river evaluations have taken place in the Southeast and the Lake Central Regions, which are in Atlanta, Georgia and Ann Arbor, Michigan, respectively. Four regional offices west of the Mississippi began their inventories early in 1979.

The primary purpose of the Wild and Scenic Rivers Act is clearly established in Section 1(b):

> *"It is hereby declared to be the policy of the United States that certain selected rivers of the Nation which, with their immediate environments, possess outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural or other similar values, shall be preserved in free-flowing condition, and that they and their immediate environments shall be protected for the benefit and enjoyment of present and future generations."*

The intent of this legislation was to develop a river conservation policy complementary to the established national policy of dam building and other construction on the rivers of the United States.

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*Mr. Eugster is an outdoor recreation planner with the Heritage Conservation and Recreation Service, Department of Interior, in Philadelphia. He headed the study described herein.*

Section 1(c) further indicates:

*"The purpose of this Act is to implement this policy by instituting a national wild and scenic rivers system, by designating the initial components of that system, and by prescribing the methods by which, and standards according to which, additional components may be added to the system from time to time."*

HCRS has interpreted this section as mandating a national river system which would be comprised of a balanced representation of the most outstanding river segments in the nation. This balanced representation has been defined as representing the various physiographic divisions, provinces, sections and river types of the United States.

The Act also contains specific criteria and requirements for potential components of the System. The requirements and criteria of the Act essentially identify four major standards that must be met for a river to be eligible for consideration in the System. The river must:

- Be free-flowing.
- Be free of certain types of significant alterations (i.e. dikes, levees, rip-rapping, channelization, etc.)
- Be largely undeveloped (rivers or sections of rivers with shorelines or watersheds essentially primitive).
- Be adjacent to a related land area that possesses an outstandingly remarkable geologic, ecologic, cultural, historic, scenic, botanical, recreation or similar value. (Interpreted to mean an area of multi-state or national significance.)

Each of these major requirements within the Act serves as a basic threshold question that must be satisfied in order for a river to be considered eligible for inclusion. These guidelines form the basis upon which the methodology for the river inventory has been developed. Each of the four requirements has been exemplified and detailed for description and evaluation purposes, using the additional criteria delineated in the Act, and in subsequent HCRS interpretations.

The study methodology used physiographic *divisions, provinces* and *sections* as the basic evaluation sub-units, with Fenneman's *"Physiographic Divisions of the United States* as the guide. Each division is further divided into provinces, and each province into sections.

In the Northeast Region, there are two major divisions, nine provinces and twenty sections.

According to Fenneman, the term "physiography" (the study of the genesis and evolution of land forms) is the approximate equivalent of geomorphology—that branch of both physiography and geology which deals with the form of the earth, the general configuration of its surface, and the changes that take place in the evolution of landforms. Physiography, and its relationship to rivers, is of paramount importance in the evaluation of rivers by any objective method. The influence of physiography on a river is expressed throughout the hydrologic cycle and is inseparable therefrom. Altitude and orientation of the basin, shape and ground slope of the watershed, topographic relief, rock type, soil mantle, and geologic structure are all important elements in determining the hydrologic characteristics of the waterway. Fenneman summarizes this relationship by saying "probably no other one thing so epitomizes the history of a region's physiography as the history of its rivers."

This relationship takes on an increased importance when one realizes that all of those elements that determine the hydrologic characteristics of a river or a river system are expressed, in their total sum, as the landscape. The landscape, more specifically the different types of scenery we see, is the total of all the physical and ecological relationships within an area.

The relative consistency of physical and natural phenomena and processes within physiographic sub-units allows for a more uniform and comparative evaluation of rivers and adjacent land areas. Since rivers, and their immediate environments, are a portion of a larger landscape—which influences and is influenced by it—it is appropriate that physiography be a basis for evaluation. The physiographic approach somewhat parallels the method used in delineating the National Park System, and allows for greater variety and distribution.

Once a river appeared to meet the criteria of the Act on paper, it was examined in more detail. Resource evaluations, including site reconnaissance using helicopter overflights, were conducted for each river to examine and document those with outstanding values. The low-altitude flights were used to photograph and videotape the river and its corridors. The Study team documented river selections, collected new and updated old information, and provided material which will assist state river programs, furnish data for briefing department and Congressional staffs, and serve as a guide for future river studies.

The following categories of information, in varying amounts of detail, were inventoried and evaluated.

*Descriptive* (Flow, length, watershed size, etc.)

*Geological-Ecological* (Unique features, endangered species, etc.)

*Wilderness* (Amount of development within the corridor, within the watershed, etc.)

*Scenic* (Views, enclosure, spatial experiences, etc.)

*Cultural* (Historic Register Sites, significant cultural landscapes, trails, etc.)

*Recreation* (Public ownership, access, proximity to population centers, fishing potential, etc.)

More than 40 percent of the rivers identified are located in three of the twenty physiographic sections. The majority of undeveloped, free-flowing rivers are located at the northern and southern extremities of the Northeast Planning Region and away from the major urban areas.

## Physiographic Sections
## Northeastern U.S.

Representative examples of undeveloped, free-flowing rivers in certain physiographic sections such as the Northern Section of the Blue Ridge Province and the Northern Section of the St. Lawrence Valley Province have been virtually eliminated. Opportunities for natural river conservation in a number of other sections, such as the Mohawk Section of the Appalachian Plateau Province and the Southern Section of the Blue Ridge Province, have nearly been foreclosed.

Geographically, as the data in Fig. 1 indicate, the majority of remaining free-flowing, undeveloped rivers (57 percent) are located in the states of Virginia, West Virginia and Maine. The rivers within each of these areas represent some of the last opportunities for the conservation of natural rivers in the northeast.

The disproportionate geographic distribution of rivers which were identified can be directly attributed to the physical characteristics of each section and the resultant pattern of land development that has taken place.

Generally, in the more rugged, steep and mountainous areas such as Blue Ridge, Allegheny and Green Mountain Sections, development—due to the restrictive topography—has occurred within the flat and often narrow river corridors. Consequently, few natural or undeveloped rivers remain in these sections. Rivers which have been identified in these areas, such as Vermont's West River, the Batten Kill in New York, or the West Branch of the Susquehanna River in Pennsylvania, usually are recognized for their *physical* characteristics—historic sites, scenic, geologic or recreation values.

In contrast, in those physiographic sections typified by the Embayed Coastal Plain, the Piedmont Upland and the New England Upland, development has generally located away from river corridors due to wetland characteristics and because of the abundance of dry, flat, upland areas which are

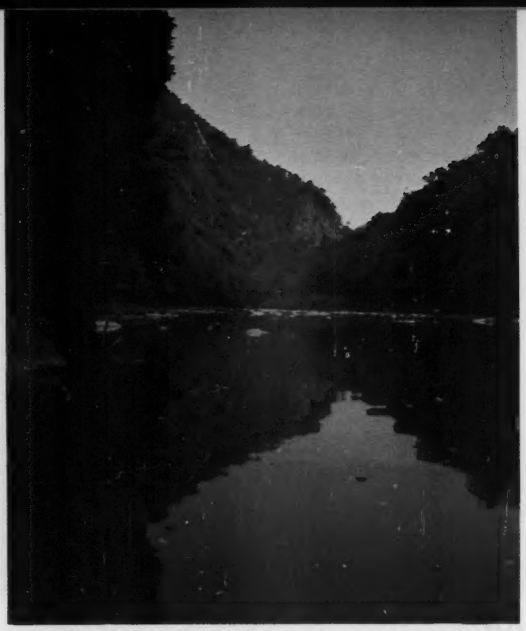
**Figure 1**

**Rivers Identified by States and Physiographic Sections**

*Mileage totals do not reflect interstate or international boundary rivers.

| State | PHYSIOGRAPHIC SECTION | Embayed Coastal Plain | Piedmont Upland | Piedmont Lowland | Blue Ridge—Northern | Blue Ridge—Southern | Ridge & Valley—Tennessee | Ridge & Valley—Middle | Ridge & Valley—Hudson Valley | St. Lawrence Valley—Champlain | St. Lawrence Valley—Northern | Appalachian Plateau—Mohawk | Appalachian Plateau—Catskill | Appalachian Plateau—S. New York | Appalachian Plateau—Allegheny Mtns | Appalachian Plateau—Kanawha | Cumberland Mtns. | Seaboard Lowland | New England Upland | White Mtns. | Green Mtns. | Taconic | Adirondack | Eastern Lake | 5,374 Total miles identified. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maine | | | | | | | | | | | | | | | | | | 173 | 662 | 214 | | | | | 1049 * |
| New Hampshire | | | | | | | | | | | | | | | | | | | | 160 | | | | | 160 * |
| Vermont | | | | | | | | | | 25 | | | | | | | | | 37 | 32 | 113 | 8 | | | 215 |
| Massachusetts | | | | | | | | | | | | | | | | | | | 11 | | 33 | 4 | | | 48 |
| Rhode Island | | | | | | | | | | | | | | | | | | | | | | | | | 0 |
| Connecticut | | | | | | | | | | | | | | | | | | | 21 | | | 32 | | | 53 |
| New York | | 11 | | | | | | | | | | 18 | 60 | 149 | | | | | | | | 10 | 181 | 79 | 508 * |
| New Jersey | | 169 | | 25 | | | | | 28 | | | | | | | | | | | | | | | | 222 * |
| Pennsylvania | | | | 4 | | | | 23 | | | | | | 40 | 250 | | | | | | | | | | 317 * |
| Delaware | | 58 | | | | | | | | | | | | | | | | | | | | | | | 58 * |
| Maryland | | 257 | 43 | 82 | | | | | | | | | | | | 5 | | | | | | | | | 387 * |
| Virginia | | 420 | 534 | 31 | 31 | 65 | 77 | 105 | | | | | | | | | 31 | | | | | | | | 1263 * |
| West Virginia | | | | | | | | 220 | | | | | | | 135 | 432 | | | | | | | | | 787 * |
| | | 915 | 577 | 111 | 31 | 65 | 77 | 348 | 28 | 25 | 0 | 18 | 60 | 189 | 385 | 437 | 31 | 173 | 731 | 406 | 146 | 54 | 181 | 79 | |

*195 miles of rivers form state boundaries; 112 miles of rivers form international boundaries.



*No other river in the northeast has the physical diversity of the Potomac.*

more suitable for human habitation and agricultural production. Consequently, numerous natural and undeveloped streams remain. Rivers identified within these areas, the St. John and the Moose Rivers in Maine, the Mullica River "system" in New Jersey, the Leipsic in Delaware and the Dragon Swamp in Virginia, usually are recognized for their *natural* characteristics—wilderness, botanic or wildlife values.

Despite the disproportionate geographic distribution of undeveloped, free-flowing rivers in the northeast, more than nine percent of the river miles identified are located in relatively close proximity—within 50 miles—of high concentrations of urban populations; cities of 50,000 or more. Rivers such as the Potomac, Lamington-Black, Delaware and Chickahominy, because of their geographic location, offer unique opportunity for "close to home" river conservation and recreation.

*The New River of West Virginia, actually one of the oldest rivers in North America, possesses some of the most challenging whitewater in the east.*

The diversity of river characteristics identified is tremendous. Segments such as the St. John River in Maine are virtually wild and extremely remote rivers, while others, the Housatonic in Connecticut is an example, possess a large amount of culturally significant development and are more accessible. Certain river segments, such as the 125 miles of Virginia's Nottoway River, are extremely long, while others, such as New York's six-mile stretch of the Peconic, are extremely short.

*Maine's St. John River—the longest and least developed river in the northeast. Shown here is the Seven-island section.*

Some rivers, the four-mile segment of the Delaware that forms the state boundary between Delaware and New Jersey for example, are large, wide, relatively slow-moving, tidal waterways. Others, such as the eight-mile stretch of Virginia's St. Mary's, are small, narrow, seasonally fast-moving headwater rivers.

Rivers within a single physiographic area may possess a blend of significant characteristics of historic, hydrologic, fish, scenic and recreation value. The Sheepscot River in Maine's Seaboard Lowland Section is a prime example. One of the most diverse rivers identified within the entire region is a 24-mile segment of the Potomac River whose banks lie between the states of Virginia and Maryland. The largest river within the northeast, the Potomac is noted for its hydrologic, geologic, wildlife, botanic, historic and recreational significance.

Certain other segments, such as the 41-mile course of Maine's Passadumkeag, have been noted for a single predominant outstanding feature—perhaps significant amounts of wetlands or water features.

Several river "systems," groups of small- or medium-sized rivers hydrologically connected, were also recognized. Paramount among these is the unique Mullica River in New Jersey. This system, which contains more than 100 miles and encompasses five river segments, flows within the nationally significant Pine Barrens area.

In a number of instances, certain river segments, due to rugged and mountainous physiographic terrain, possess parallel roads adjacent to or within the river corridor. The Connecticut River in Vermont and New Hampshire and the Androscoggin River in the latter state are typical. Although these roads detract from the natural character of the segment, they often afford easy access—both physical and visual—to the river.

The states of New York, Pennsylvania and Virginia, because of the breadth of physiographic sections within their political boundaries, offer a wealth of differing river types. More than 70 percent of all river "types" necessary for a balanced and representative System in the northeast region are present within these three states.

More than 85 percent of all the rivers identified are medium- to small-sized. Undeveloped, free-flowing, large (high order) rivers—those rivers with the greatest size and most constant flow features—are extremely rare. In fact, only about 825 miles of large rivers such as the Potomac, the Penobscot, the Delaware and the St. Croix remain in an undeveloped and free-flowing condition. The Study indicates that as river size increases, the number and diversity of interests competing for its use increase. Not surprisingly, all of the large, high order rivers identified are presently also being examined by a variety of public and private interests for non-conservation uses.

Certain rivers within the purview of the Study flow through a number of different physiographic sections and thus offer an opportunity to recognize and conserve several representative river types along the same waterway. Although two-physiographic-section rivers abound—the James and Nottoway in Virginia; the Sheepscot and Machias in Maine, the Westfield in Massachusetts—no waterway can compare with the diversity of the Potomac. Comprising more than 180 miles, within eight segments, the Potomac is the largest free-flowing, undeveloped river in the northeast. It flows within five physiographic sections and the states of West Virginia, Virginia and Maryland.

Three rivers in Maine, within the Seaboard Lowland and the New England Upland Sections and totaling nearly 120 miles, form a portion of the international boundary between the U.S. and Canada. The Missisquoi River, in the state of Vermont and the Green Mountain Section, is a 25-mile segment which begins in the U.S. and flows into Canada. Neither Maine nor Vermont have a river program to recognize or protect these rivers.

Approximately 365 miles of rivers, representing eight physiographic sections in the Northeast Region, are interstate. An additional 195 miles form state boundaries. The majority of these rivers, which include the Potomac, the Delaware, and Conneaut Creek in Ohio and Pennsylvania, are within states having legislated Wild and Scenic River Programs, although, with one exception, none of these boundary rivers are recognized or protected at present.

*Flowing largely through a Department of Interior wildlife refuge in Maryland, the Blackwater River is characterized by vast tidal marshes, hummocks and meandering channels.*

Nationally, the northeast has fewer rivers in the National Wild and Scenic Rivers System than any other area in the continental United States.

Three river segments, representative of four physiographic sections within the Northeast Region, are in the National Wild and Scenic Rivers System. The Delaware, 64 miles long from Hancock, New York to below Cherry Island, New York, flows within the Catskill and Southern New York Sections of the Appalachian Plateau Province and the states of New York and New Jersey. Thirty-seven miles of its length—from the southern boundary of the Delaware Water Gap National Recreation Area to Port Jervis, New York, flow within the Hudson Valley Section of the Ridge and Valley Province and the states of Pennsylvania and New Jersey. The two Delaware segments are high order rivers. The Allagash River, 92 miles long from Twin Brook Rapids to the Telos Dam, flows within the New England Upland Section of the New England Province.

A number of states in the northeast have established their own river programs, with varying amounts of success. Approximately 1840 miles of rivers have been designated by the state river programs of Maryland, New York, Virginia, Pennsylvania and West Virginia in the Northeast Region. Of the rivers identified in the System Study, approximately five percent—300 miles—are also designated components of state systems. With the exception of Maryland, the five states have designated a minimal variety of rivers. In total, only seven of the 23 physiographic sections of the northeast are represented, and almost all of the state rivers are small- or medium-sized. Maryland's nine designated rivers, which total about 440 miles, flow within the Embayed, Piedmont Upland, Piedmont Lowland, Northern and Allegheny Mountain Sections.

New York's state-designated rivers fall into two distinct categories—those within the Adirondack Park and those outside. Significantly, within the state-owned Park, nearly 1200 miles of rivers have been designated, while only about 16 miles of streams have been tabbed in the remainder of the state. Virtually all of the 68 designated rivers in the Park flow within the Adirondack Province, while the 16 miles on two rivers outside are within the Embayed Section.

Pennsylvania's only designated river, the semi-urban Schuylkill, flows for 93 miles through the Piedmont Upland Section. West Virginia's five named waterways, totaling 205 miles, flow in close proximity to each other in the Kanawha Section and offer a variety of whitewater areas. Virginia's 86

*The Delaware River (southern N.Y. portion), a unique high order river, is one of only three rivers in the northeast which are in the National Rivers System.*

*Certain rivers, such as the Sugar in New Hampshire, were eliminated from consideration during the study due to development along their banks. Many of these types of rivers, especially in New England, are culturally significant, however.*

*Proposed non-conservation projects, such as this nuclear power plant on the Potomac River in Maryland, threaten most of the remaining large rivers in the northeast.*

miles, also on five rivers, flow within the Piedmont Upland Section of the state and generally tend to be a combination of relatively short segments and comparatively small rivers.

The oldest state-designated river in the northeast is the aforementioned Allagash in Maine. Maine, which does not have a rivers program, designated the high order Allagash prior to applying for and receiving Federal recognition of the Allagash as a state-administered national river. No river in the northeast has received both state and Federal river designation, except the Allagash.

Unfortunately, more free-flowing rivers in the northeast are threatened than are protected. *All* of the Study-surveyed river segments in the northeast region are threatened by some form of adverse land use development. More specifically, nearly 2000 miles of the rivers identified are presently slated for some form of non-conservation land and water use which would have a significant negative impact on river values. Existing and proposed developments that are impacting on, and could change, the free-flowing, undeveloped and outstanding character of these rivers and river segments range from such massive water uses as nuclear power and hydro-electric plants, flood control dams and reservoirs, to minor land uses such as sand borrowpits, second home developments, logging, channelization and private recreation development.

The most common "threats" to undeveloped and free-flowing rivers in the northeast region are water supply projects and flood control dams which immediately threaten the condition of approximately 640 miles (11 percent) of all the rivers identified. Not surprisingly, the majority of the known projects or activities that presently threaten the identified rivers occur within the Embayed, Piedmont Upland and New England Upland physiographic sections; those areas with the most undeveloped, free-flowing river mileage in the northeast.

The characteristics of the river corridors within each physiographic section will dictate the type of fee or less-than-fee acquisition strategy which will be appropriate to use to preserve a river. Certain sections and river corridors are more amenable to certain strategies than others and no one conservation approach is suitable regionwide.

Rivers and river corridors within most of the rugged physiographic areas—due to the topography, public ownership and lack of land development within the narrow river corridors—are amenable to specific conservation strategies, including preservation as special historic and aesthetic districts, national and state historic landmark status, scenic view-shed ordinances, building setbacks, and scenic highway designations.

In those sections dominated by wetlands, high water tables and flood plains, conservation action such as wetland regulation, floodplain zoning, rare and endangered plant and animal location designation, shoreland zoning, and critical area protection may be appropriate.

The major benefits of the System Study, then, include:

- Identifying river resources—Locates the most significant natural, cultural, urban, recreation and scenic rivers and describes why they are important.
- Making information available—Provides river conservation interests with subjective, comparative and descriptive data about rivers, including visual aids.
- Identifying opportunities for river preservation—Describes resources that dictate land use policy decisions, identifies conservation support groups and potential mitigation situations.
- Building a communications network—Establishes (through the cooperation of the states) a forum for communication about river conservation at all levels of government and within the private sector.

*The Youghiogheny River in Pennsylvania, particularly near this falls in Ohiopyle, is popular for canoeing and rafting.*

*Winding through the picturesque Blue Ridge Mountains, Big Reed Island Creek is the largest remaining free-flowing river in this section.*

- Identifying local and state issues and river preservation supporters—Gathers information about specific river-related issues, (i.e. threats, political positions, major plans, etc.) and supporters and opponents of preservation.
- Answering questions about designation—Begins to assess the effects of designation so that river interests can better evaluate strategies and remove impediments to river preservation.

This inventory and evaluation of rivers is to be used as one factor in determining suitability for further study and/or potential inclusion into the National System. Other aspects, not addressed here, include the political will of the states and the attitude of local governments and landowners.

The list of rivers, and the data compiled by the System Study, provides the Department of Interior, other Federal agencies, Congress, state and local governments and the private sector with an objective, comprehensive information base. This information can be used to better assess the implications of activities relating to our nation's undeveloped rivers. ■

*The Great Falls area of the Potomac, only ten miles from the nation's Capitol, is frequently used for rock climbing.*

*The aftermath of the 1978 fish kill along Rush Creek. Nearly 100,000 fish were destroyed, including an estimated 10,000 trout.*
(Photo by Mel Haugstad)

by James A. Schneider

On May 20, 1978, a trout stream died. It didn't wither away or expire after a long illness. It died suddenly and shockingly. In less than a day, one hundred thousand fish—including 10,000 trout—littered the bed and shorelines of Rush Creek, a southeastern Minnesota trout stream. Thirteen miles of trout waters were destroyed in the course of a few hours.

Gone, too, were the aquatic insect larvae so necessary in the stream ecosystem. The only survivors appeared to be the stream inhabitants that found shelter or were fortunate enough to live in the springs feeding the creek.

Phones rang at the Minnesota Department of Natural Resources (DNR). What happened, the callers asked? Who did this? Why?

The DNR field staff was not surprised at the news, although this was the worst case recorded so far. Many other streams in southeastern Minnesota had suffered similar fates during recent years. Duschee Creek, another trout stream favored by many fishermen, was "mysteriously" killed during June 1974.

Mel Haugstad, the fisheries field manager in the problem area, keeps a very close watch on his trout streams—especially the good ones. Over the years of electrofishing, stocking, observing fishing pressure and success and just plain keeping an eye on things, Haugstad has become convinced that whatever is causing the sensational kills is also causing problems on a smaller scale. Rumors of dead fish being sighted here and there are common throughout the year. Fish assessments show small or zero populations where there should be healthy, vigorous fish.

When the Rush Creek kill was reported, field personnel were alerted and an investigation began. The first fact uncovered was that the kill was actually several days old. Fresh specimens for examination and testing would not be available—a very important and discouraging fact.

Readers from heavily populated regions of the country and/or with intensively managed fisheries will wonder how a major fish kill such as this could go "unnoticed" for four days. The fact is, southeastern Minnesota contains hundreds of small streams. About eighty of these have stretches of trout quality water. Only two small fisheries management stations are located amongst all this aquatic wealth. The adverse weather was also a factor—not many people were out and about over that weekend.

Some dead fish specimens were gathered in spite of their being several days deceased, as it was hoped that the fisheries pathologist in St. Paul might get something from an internal examination. Water samples were also taken for chemistry laboratory examination, but again little hope was held that anything definite would be found.

The biologists looked for common denominators. Was there a thread connecting these recent kills? Rainfall heavy enough to cause washing and erosion from row crop fields seemed to be a common denominator. The severe (and mysterious) kills also appeared to occur during the same period of the year—May planting time.

For several days preceding the Rush Creek kill, corn planting activity was heavy. The pungent odor of agricultural chemicals applied with the corn had permeated the country air all week. Could something applied to the fields be causing such severe problems in the streams? "Most definitely!" stated biologists. "Hold on, there!" protested farmers. "Foul" warned chemical manufacturers.

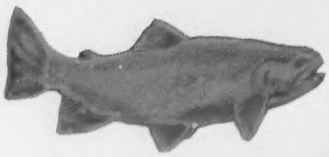
It quickly became apparent that if the biologists were to pursue this line, diplomacy and care would be necessary. In Minnesota, public employees can be sued and made to pay damages; even for work-connected errors. It wouldn't do to issue statements regarding suspicions until or unless the findings were quite definite.

The water tested by the laboratory was as expected—completely innocuous. The fish specimens examined by the pathologist, however, were another matter. His report stated, "The examinations and preliminary tests made from samples of moribund (dying) and dead fish . . . collected at Rush Creek and Garvin Brook (a nearby stream which also suffered a partial fish kill during this event) near St. Charles, Minnesota, are consistent with a presumptive diagnosis of acute poisoning." Important and informative, but not enough to pinpoint the actual cause.

Naturally, the fisheries managers were frustrated. The citizens of the state were not very happy either, and not just the trout fishing fraternity. Phone calls and letters poured in as a result of media coverage. Obviously, time had come to do more than just count dead fish. After several staff level phone calls, it was decided to assemble the expertise of trained and experienced people from several pertinent agencies. Phone calls were made and letters mailed.

The response was immediate and gratifying. Attendees would be

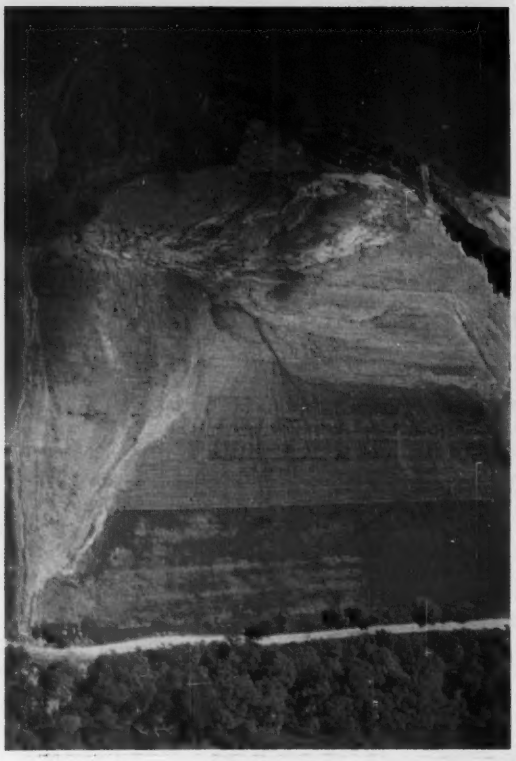
*Mr. Schneider is a regional fisheries supervisor with the Minnesota Department of Natural Resources, Rochester, MN 55901.*



present from the Agricultural Extension Service, the Environmental Protection Agency (EPA), the Federal Fish and Wildlife Service, and, of course, personnel within the Minnesota Department of Natural Resources. The Minnesota Pollution Control Agency expressed interest but wished to be kept informed rather than become involved. The first meeting was held in December, 1978, and was well attended. The problem was described by the chairman and discussion was quickly underway.

It was agreed that a sampling program was needed. The parameters that should be measured were discussed—then the parameters that *could* be measured (because of personnel and funding limitations) were agreed upon. The Minnesota DNR would provide the field help necessary for reconnaissance and field testing. The DNR lab is equipped to test water for "carbamate"-based insecticides and would run those samples. Samples to be tested for other insecticides (especially organophosphate-based) would be sent to a contract laboratory or to the National Fisheries Research Laboratory at Columbia, MO. Other parameters to be measured, if feasible, would be pH, temperature, turbidity (suspended soil particles), ammonia and dissolved oxygen. (This did not work well in practice. Because of the rapidity in which these (flash) floods pass, most testing effort was found to be futile. If it is decided that more intensive sampling is necessary, it will require special priority effort.)

One of the most interesting ideas to come from the meeting was proposed by Robert Glaser, head chemist for the Minnesota Fish and Wildlife Laboratory. He claimed he could develop a simple field test for detecting cholinesterase inhibition (an indication of toxic activity), and was quickly assigned this important and innovative task.



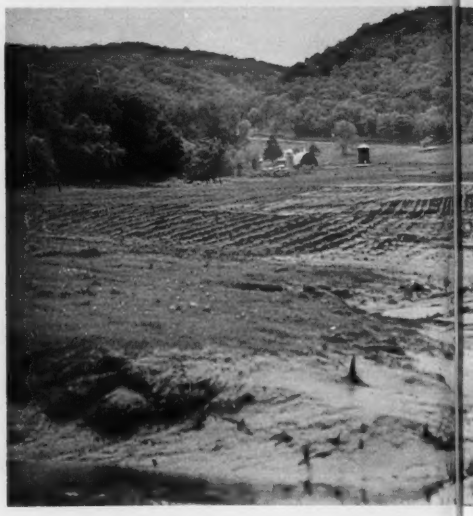
*An aerial view of severe farmland erosion in a southeastern Minnesota trout stream valley.* (Photos by the author.)

*Worsening cropland erosion in Minnesota's East Indian Creek Watershed.*

*Cornfield runoff entering directly into Rush Creek.*

The Agricultural Extension Service was assigned to gather information regarding types and amounts of agricultural chemicals being used in the target watersheds (Rush Creek and Duschee Creek). The EPA people were to stand by and help out as needed with advice or equipment. The state fish and wildlife pathologist would develop a list of steps to follow in selecting, handling and shipping specimens for his needs. Equipment and supplies would be inventoried to ascertain what would be needed by field personnel for actual sampling. Training was also discussed but delayed until such time as the techniques and parameters were decided upon.

A second and final meeting was held by the same committee during



*Organs from a brown trout taken from Pine Creek on June 8, 1979, showing abnormalities, particularly in the color of the liver and heart. Histological (tissue) examination also disclosed capillary rupturing.*

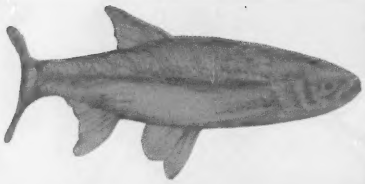
March, 1979, when final plans were made. Glaser was confident he would have his field test method perfected by May.

During both meetings there was lengthy discussion centering around the question of what the finds would or could be used for. If suspicions regarding insecticides proved valid, what next? Would there be grounds for prosecution? Ammunition for mandatory land management regulations? Or just another sales tool for the Soil Conservation Service?

By May 1979, the time had come to wait. Personnel and equipment were ready. All that was lacking was some heavy rain in the target watersheds. A late spring moved planting back two and three weeks. Finally, on June 1, spring storm systems began passing through the region. Following is the actual field report covering the first two heavy runoffs:

*Wednesday, May 30*—Moderate to heavy rainfall occurred in target watersheds. The Rochester office was notified of dead fish in Rush Creek headwaters by Barry Morse, Area Forester, at 8:30 a.m. Reconnaissance of the watershed by Ron Payer and the author began about 9:30 a.m. Eight dead white suckers were counted on the banks along an estimated 500 feet of stream. The fish were juveniles (4″-8″) and most were stranded several inches above the receded water level, indicating that the fish had succumbed some hours prior to the investigation. No moribund fish were found. Silt deposited on stream banks was evidence of field erosion. Since the kill was slight and not fresh, no samples of fish or water were processed.

Reconnaissance continued that day along Rush Creek to its junction with Pine Creek, then upstream on Pine Creek to Coolridge Creek. No dead fish were noted at the several check points close to the road.



A fish kill of indeterminate proportions was reported three days later by a landowner on Pine Creek in the vicinity of its juncture with Hemmingway and Coolridge Creeks. This kill was comprised (reportedly) of white suckers and other minnows and probably occurred sometime Thursday or Friday (May 31-June 1). This kill, if present at the time, was not noted during the reconnaissance effort by Payer and the author on Thursday, May 31.

*Friday, June 8*—Heavy rains occurred during the preceding night.

A fish kill was noted on Pine Creek by Barry Morse, who was on arranged reconnaissance. The Rochester office was notified by mobile radio about 8:30 a.m., Friday, June 8. An immediate investigation was begun by personnel from the Lanesboro Area Fisheries Station, Rochester Regional Fisheries Office, and the State Fish and Wildlife Chemistry Laboratory at Forest Lake.

Reconnaissance during the day found the kill was comprised largely of white suckers, with lesser numbers of other minnows and sculpin. A farmer along Pine Creek observed that a "heavy" fish kill had also occurred on the previous day when the creek waters were first rising, but that "windrowed" fish (mostly suckers, according to the farmer) were swept along by the following floodwaters. For this reason an accurate count of dead fish was not made on Friday, June 8, since such an effort was felt to be redundant and could result in misleading information.

## Methods

Both moribund and freshly killed suckers were selected for testing, using the method developed by Glaser and the staff of the Forest Lake Laboratory. Simply, it consists of exposing the brain tissue of the specimen to a chemically treated, felt-like "ticket". The color changes that follow indicate whether

*One year after the massive fish kill of 1978—and subsequent restocking—a fisherman pursues trout on Rush Creek.*

cholinesterase inhibition activity is occurring, and to some degree the level of that activity. Other field tests included a gross physical and morphological examination of specimens. Samples of fish and water were also taken for further laboratory study.

One trout was captured within the kill sector by electro-fishing. This fish was processed and tested. Control fish (brown trout) from the Lanesboro Fish Hatchery were brought along that morning and were also tested.

## Results

The "treated ticket" field procedure developed by Glaser and his staff was an unqualified success. Fish tested in the field were: two white suckers from Pine Creek (one moribund and one freshly dead), one brown trout from Pine Creek (live-captured with an electro-fisher), two brown trout from the hatchery (controls) and two brook trout from Coolridge Creek. Several kill specimens were also transported back to the fish and wildlife pathology and chemistry laboratories for further testing using standard procedures.

The brook trout from Coolridge Creek and the hatchery trout tested negative (no cholinesterase inhibition). (The two small brook trout were the only dead fish in evidence on Coolridge Creek, and could have been victims of fishing (hooking) mortality.) The two white suckers and the brown trout all tested positive. Later testing in the chemistry laboratory using standard methods and techniques also indicated severe inhibition occurring in fish from Pine Creek.

Preliminary examinations in the biology and chemistry laboratories of the Minnesota Fish and Wildlife Division reaffirmed the field analysis: Death due to poisoning—most probable suspect(s) being organo-phosphate-based insecticides used for controlling corn rootworm larvae.

An explanation of how and why cholinesterase inhibition is used to arrive at cause of death should be given. One of the best the author has

*Poor farming practices, such as this example in the Rush Creek Watershed, hasten erosion and subsequent runoff.*

*An excellent example of good farming practice so rarely found in southeastern Minnesota. Note terracing to retard erosion.*

*Chemically treated "tickets" developed for the cholinesterase inhibition field test. The color change to green indicates no cholinesterase inhibition occurring.*

read is included as part of the fish pathology report prepared by Phil Economon, Minnesota's fish and wildlife pathologist: ". . . tests run by the chemistry laboratory demonstrated these fish had abnormally low levels of cholinesterase. This enzyme, which is normally present in all body tissues, is responsible for hydrolyzing acetylcholine into choline and acetic acid. This is an important biochemical process especially for the transmission of nerve impulses and the operation of the sympathetic and autonomic nervous systems.

"This enzyme is inhibited or depressed in cases of severe infection, anemia, malnutrition, liver disease, and insecticide poisoning. All but the last consideration have been ruled out in the course of this examination. . . .

"In the absence of any acute or chronic pathology to explain the depressed cholinesterase enzyme activity or the histopathological changes described, I am inclined to put the cause of the fish kill at Pine Creek down to poisoning, on the basis of a potent pesticide chemical that probably washed into the stream from surrounding agricultural farm lands during the recent heavy rains . . ."

Many modern pesticides are designed to be short lived—to do their job and disappear. Exposure to certain conditions, such as being incorporated into a living system, will "break them down" even faster. In the case of poisoned fish, for instance, it is usually an exercise in futility to look for the actual chemical compound that caused the mortality. Rather, one must evaluate its effects on the system. Thus, the cholinesterase inhibition test.

As of this writing, meetings are already being planned for determining what steps can or should be taken next. Many agencies will be involved since the problem overlaps boundaries of responsibilities. More research and information is needed. For instance, perhaps a less destructive insecticide is available for use in high gradient farming operations. Without mentioning brand names, our investigation did reveal that a particularly "hot" organo-phosphate-based insecticide was commonly used throughout the watershed. Perhaps something a little "cooler" would work as well. Application methods could also stand a closer look. Sloppy planting practices could leave these dangerous chemicals vulnerable to even slight runoffs. If true, this could be corrected under existing authorities.

The chemical companies are concerned as well. They realize that improper or uninformed use of their products can damage their reputation and turn public opinion against use of farm chemicals. This would affect their profit structure—a distinctly unpleasant thought to any corporation executive.

The challenge is obvious; the solution will take some real cooperation. Integral in any cooperative effort will be the farmer. Readers who feel they might have something of value to contribute to the solution are welcome to write the author. Ideas, even remotely feasible, will certainly be inserted into future discussions. ■

*Deep drilling operations aboard the* Glomar Challenger.

# Deep Ocean Drilling

by Roger Revelle

The fundamental doctrine of American geology in the late 1940s was that the continents and ocean basins had been permanent features of the earth's surface, almost since the beginning of geologic time. The crust of the earth beneath the sea was unimaginably old, and the continents had always been about where they are today, though they had probably grown in size over several billion years. The differences in elevation between the sea floor and the continents had perhaps slowly become greater over the geologic ages, as the volume of sea water increased.

When the flat-topped sea mounts of the Central Pacific were first discovered by Harry Hess it was thought they must have been slowly submerged over the last two billion years. It was believed that sediments had gradually but steadily accumulated on the deep-sea floor throughout all this time. The most learned and mathematically able geophysicists published conclusive demonstrations that continental drift was impossible, because of the known physical properties of rocks.

These doctrines received an abrupt shock in 1950 when shallow-water reef corals only about a hundred years old were found on the flat-topped sea mounts of the Mid-Pacific Mountains at depths of two kilometers, and when seismic refraction studies by Russell Raitt indicated that the deep sea sediments over vast areas are only one or two hundred meters thick.

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*Dr. Revelle is Professor of Science and Public Policy, University of California at San Diego. This article is adapted from his October 1978 address at the Joint Oceanographic Institutions, Inc. dinner commemorating the 10th anniversary of deep sea drilling.*

Others believed that somewhere in the deep sea there was a place where sediments of all geologic ages, back to one or two billion years, had been deposited one on top of the other, and that all these sediments were still there, in what earth scientists call a complete geologic column—in effect a complete book of records of most of the geologic history of the earth.

Now, less than two decades later, we know that none of these doctrines even faintly resembled the truth. Far from being as old as the earth, the oldest rocks on the ocean floor are less than 4 percent of the earth's age. One of our planet's major oceans, the Atlantic, did not even exist 200 million years ago. The six continents we know today were born and attained their present location by the fragmenting of a single giant continent, and the subsequent gradual but steady motion of the fragments in different directions over and through the ocean floor.

Ten years ago the new ideas that we now classify under the heading of plate tectonics were a reasonable but startling hypothesis, which offered an integrated explanation of many kinds of observations of the earth—including analyses of seismic waves, measurements of gravity, magnetism, heat-flow, delineations of undersea topography, and the fitting together of the continental margins on the two sides of the Atlantic. But the direct proof of this hypothesis from actual samples of rocks and sediments has come about very largely from the last decade of research; the ten years of probing into the sea floor by the Deep Sea Drilling Project. This drilling, perhaps the greatest achievement in the entire history of the earth sciences, has had some definitive results:

■ *Demonstration of the extreme youth, in geologic terms, of the earth's crust beneath the sea.*

The oldest rocks found in any of the 460 bore holes during ten years of drilling are between 150 and 200 million years old.

■ *Parts of the ocean crust have moved horizontally for great distances, away from the zones of crust formation along mid-ocean ridges.*

This is shown by several lines of evidence in the cores of sediments and rocks obtained by the drilling. Three of these are related to the distribution of organic remains, magnetic dip, and times of deposition, respectively.

First, in the topmost layers of sediment, a high concentration of organic remains occurs in a narrow band right along the equator, owing to the high organic productivity of the sub-surface equatorial waters. In the Pacific, this narrow band is found at progressively greater distances north of the equator with increasing depth in the cores, e.g. with increasing sediment age. These older sediments must have been deposited underneath the equator and afterward moved northward to their present position; the older the sediments, the farther they have moved from the equator.

Second, the remaining magnetic dip of older sediments and the underlying rocks in many cores is greater or less, depending on the north-south component of their horizontal displacement since they were deposited, than the dip corresponding to their present position relative to the earth's magnetic pole.

Third, sediments of progressively greater age directly overlie the basaltic basement at increasing distances from the zone of formation of the basalt along the mid-ocean ridges.

These and other lines of evidence indicate that the horizontal velocities of the crustal motion have been between 1 and 13 centimeters per year, and that parts of the sea floor have moved several thousand kilometers during the past 200 million years.

■ *As it has moved away from the mid-ocean ridge, the sea floor has subsided relative to the ocean surface.*

This is shown by older sediments in the drill cores, which were laid down in much shallower water than the depths at which they were found. The older the sediments, the shallower the site of the deposition, up to the original depth of the mid-ocean ridge. The rate of subsidence has been 60 to 100 meters per million years. Presumably, this subsidence resulted from contraction due to cooling of the sub-oceanic rocks, as they moved away from the zone of magmatic activity along the mid-ocean ridge. It is possible also that portions of the continental margin in the Atlantic and elsewhere have foundered as they were torn apart by rifting.

■ *The existence of salt domes, which may have acted as traps for hydrocarbons, in the bottom of the Gulf of Mexico.*

The salt was presumably laid down as an evaporite in the early stages of subsidence of this basin, and was afterwards forced upward through the overlying sediments in giant plugs.

■ *The drying up and later refilling of the Mediterranean Sea.*

Massive salt deposits, laid down between 5 and 12 million years ago, are found in cores from the Mediterranean. Evidently, the entrances to the Mediterranean were blocked during this period and the water in the basin evaporated, forming a huge, mile-deep depression, five times as far below sea level as the present Dead Sea,—the deepest spot on earth today—and as large in area as the Indian subcontinent.

■ *The growth of the Atlantic Ocean from a series of narrow stagnant basins into the broad ocean of today.*

The oldest sediments in the Atlantic are black shales, salt deposits, and cherts, occurring in limited areas on or near the continental margins.

■ *Past climatic and ecological changes in the ocean.*

Studies of the sequences of marine fossils found in the cores have contributed greatly to the construction of a geological and evolutionary time-table for all parts of the world ocean, to precise correlation of different types of

fossils representing different marine ecosystems and to an understanding of the paleo-climatology of the ocean.

■ *Discovery of resource-rich deposits.*

New oceanic crust formed along plate margins is hydrothermally altered by circulating sea water, resulting in some areas in the formation of deposits with high concentrations of valuable metals. Along both active and passive continental margins, marine sediments and their contained organic matter are apparently metamorphosed by heat and pressure, with possible formation of fluid hydrocarbons.

■ *The age of the Antarctic icecap.*

Sediment cores from high latitudes in the Southern Ocean indicate that Antarctica was covered by ice 20 million years ago, and that the ice cap was much more extensive 5 million years ago than at present. At that time worldwide sea levels were about 15 meters lower than today.

■ *The fixed location of a "hot spot" in the mantle.*

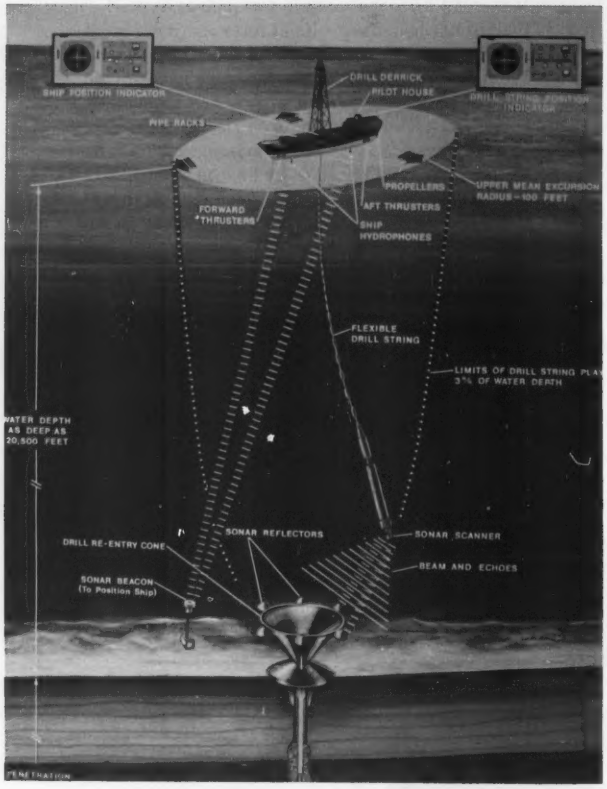
Paleontological and magnetic evidence indicates that the Emperor sea mounts in the northwest Pacific are a continuation of the Hawaiian Island chain, and that all these elevated portions of the sea floor were formed by volcanic activity near the present position of the island of Hawaii. The northernmost of the Emperor sea mounts is the oldest, formed about 70 million years ago, and the ages become progressively younger toward the south and southeast. The first motion of the sea floor away from Hawaii was to the north, and later the direction of motion shifted toward the northwest.

## Deep Sea Drilling Project

To an old-fashioned oceanographer like myself, the technical and engineering accomplishments of the Deep Sea Drilling Project seem as remarkable as the scientific ones. The drilling ship, *Glomar Challenger,* is not fastened to the sea floor in any way, but simply floats freely at the surface. The only means of communication between the ocean bottom and the people on the ship is by underwater sound and the behavior of the drill string.

The Glomar Challenger.
*(Unless otherwise stated, photos courtesy of the Deep Sea Drilling Project.)*

## Dynamic Positioning and Re-Entry




Yet, with a sonar transponder planted on the sea floor, a series of sonar receivers at different points on the hull, and powerful thrusters which can move the ship in any direction, all in a computer-linked system, it is possible to maintain the ship for months at a time within about a hundred feet of a fixed geographical position.

When the project began, the drilling bit and drill stem could not be put back into the same hole once they had been pulled out. This meant that when the bit wore out, as it does quite quickly in rock drilling, the hole had to be abandoned. Now it is possible to re-enter the same hole as many times as desired. The difficulty of doing this can be imagined when one realizes that a string of drill pipe 15 to 20 thousand feet long is exactly that—a string which bends and twists as if it were cotton rather than steel, subject to every current and vagary of motion all the way from the surface to the bottom.

During a recent cruise, the drill string was pulled out of a hole that had been well started, and the ship sailed to a port more than 1000 miles away, for repairs. After the repairs were accomplished, the ship returned to within a few hundred feet of the hole, located the bottom-mounted sonar transponder, re-entered the hole, and continued drilling.

The Deep Sea Drilling Project is an example of Big Science with a capital B. But in terms of results obtained and numbers of scientists involved, it has been fairly inexpensive.

Thirty miles of cores have been recovered from a total length of holes drilled of nearly 100 miles. Ninety thousand core samples have been distributed to over 800 separate investigators, from 253 academic, industrial, and government organizations. About half of these investigators are American and the other half are citizens of other countries. Four hundred and eighty scientists have participated in the work at sea; 360 others have been members of Joint Oceanographic Institutions Deep Earth Samples (JOIDES) advisory panels; an additional 600 have contributed to the *Initial Reports* of the project and more than 800 have made subsequent requests for samples. In all, at least 2000 scientist-years have been devoted to the project.

The cost of the project for the years from FY 1967 to FY 1980 will be 137 million dollars. Given that more than 55 million words have been printed on the project, this corresponds to $2.50 per published scientific word and less than $60,000 per scientist-year.

What about the future? In spite of its impressive accomplishments, the Deep Sea Drilling Project has almost literally gone little farther than to scratch the surface of the ocean floor. Holes have been sunk at 460 locations to an average depth of 300 meters, roughly 1000 feet. This is one hole for every 800,000 square kilometers of the sea floor. Eight hundred thousand square kilometers represents an area about equal to that of California, Oregon and Washington, combined. How much could we expect to know about these three states if we only had core samples from one hole drilled to a depth of 1000 feet? Our conclusions would be vastly different if the hole were drilled in the Sierra Nevada, the San Joaquin Valley, or the Coast Ranges.

The deepest penetration into the ocean floor was about 5700 feet, a little more than a mile. This is less than one-fourth of the thickness of the oceanic crust. The greatest depth of water was 24,000 feet. Yet, some of the most interesting places in the ocean—the great deep sea trenches—are around 35,000 feet deep.

Though much remains to be done within the limited capability of *Glomar Challenger*, the drilling technology has now been developed to the point where a larger ship (the *Glomar Explorer* concept), capable of drilling in deeper water, penetrating further beneath the sea bottom, and suspending much heavier loads from the drilling platform, could be effectively used. These greater drilling capabilities are needed to take advantage of the scientific opportunities revealed by the work already done.

*White dots mark drill sites throughout the world's oceans. (After Heezen and Tharp.)*

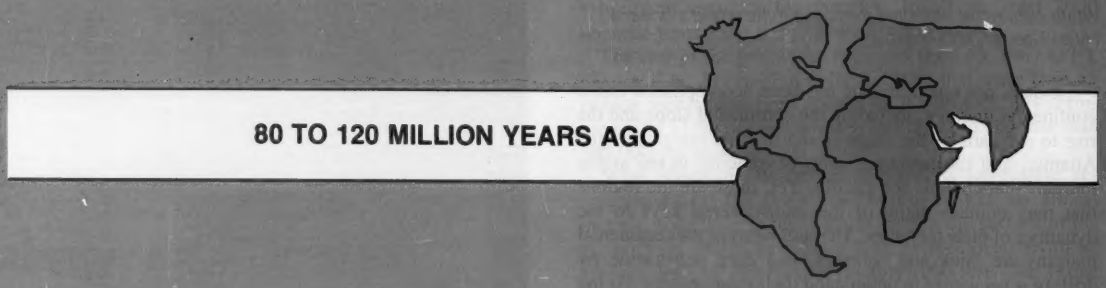
To date, not much drilling has been accomplished in the continental margins, including the continental slope and the rise to seaward of the slope in the passive margins of the Atlantic, and the landward sides of trenches in the active margins that encircle the Pacific. Yet, these are the regions that may contain many of the undiscovered keys to the dynamics of plate tectonics. The sediments of the continental margins are thick and complex, and deep penetration by drilling is necessary to understand their relationships. At the same time, these sediments may contain liquid and gaseous hydrocarbons, and the danger of pollution requires that heavy auxiliary equipment be used to prevent blowouts.

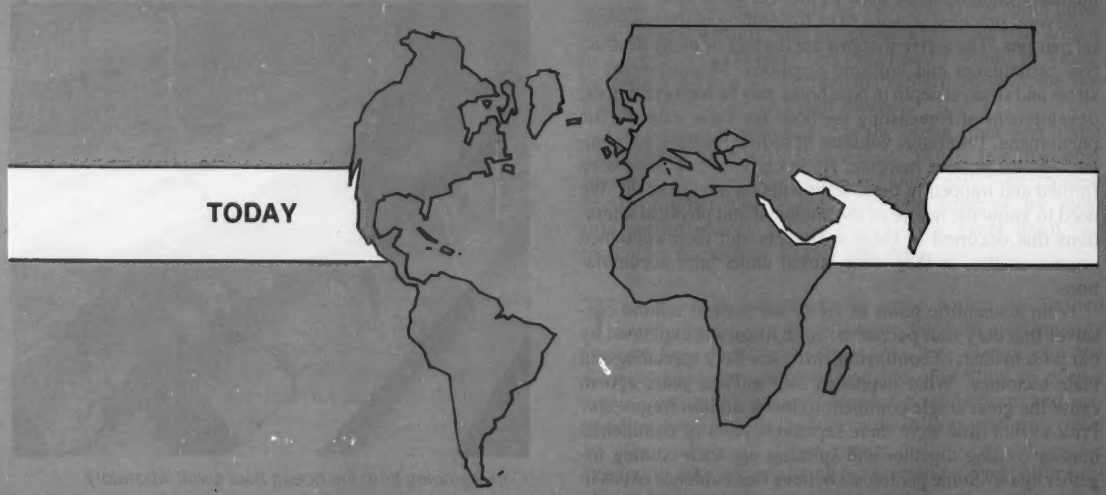
Several practical reasons exist for drilling in the continental margins. The active margins are the loci of many destructive earthquakes and volcanic eruptions. Measurements of stress and strain at depth in bore holes may be important in the development of forecasting methods for these catastrophic phenomena. Enormous volumes of sediments have accumulated on the passive margins. Hydrocarbons may have been formed and trapped in these sediments on a large scale. We need to know the nature of the chemical and physical alterations that occurred in these sediments and their contained organic matter, as they were buried under later accumulations.

From a scientific point of view, we need to remind ourselves that only four percent of earth history is explained by our present ideas of continental drift, sea-floor spreading and plate tectonics. What happened 200 million years ago to cause the great single continent to break up into fragments? Prior to that time were there repeated cycles of continental masses coming together and splitting up, then coming together again? Some geologists believe that evidence exists in the continents for such a series of events.

*Core samples from the ocean floor await laboratory analysis.*

## Continental Drift and Sea-Floor Spreading

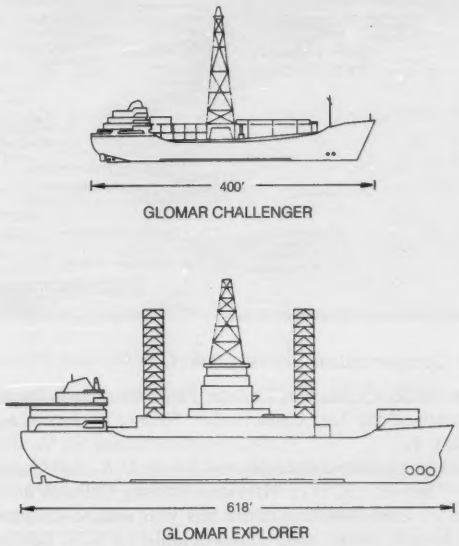


But an alternative is at least possible. Could only one continent have existed throughout a major part of the earth's lifetime, gradually growing in size by accretion of ocean crust to the edges, until finally it grew so large that it became unstable and could no longer remain in one piece? If this was the case, the last 200 million years have been unique in the history of the earth.

The coast of North America now intersects a zone of active crustal formation. Was this same zone formerly located at a distance from shore and subsequently moved laterally, relative to the continent, to its present position? Or has a new axis of spreading formed and extended northward into the land? A similar question can be asked about the spreading axis that now lies along the Mid-Atlantic ridge. If this existed prior to 200 million years ago, it was in the center of the single giant continent referred to earlier. Did it form there, and if so how? Or did the split occur as an extension of an active spreading axis in the ocean which crept under the continent?

If questions about events prior to the splitting of the single giant continent can be answered, it will only be by a deeper understanding of the geologic history of the continents, for only the continents contain a record in the rocks of the early history of the earth. But to understand this record we need to know a great deal more about the processes that are now occurring, and have occurred in the relatively recent geologic past, in the continental margins.




*The* Glomar Explorer, *proposed as the "second generation" of deep sea drilling ship, can handle more than 10 kilometers of drill pipe in contrast to the 7.6 kilometers for the* Challenger. *In addition, the* Explorer *can operate in waves that are 12 meters high and in winds of 65 knots, as well as in ice-covered polar seas. It is too large, however, to pass under bridges or to transit the Panama Canal.*

Insofar as possible, the objective of future drilling must be to answer well-formulated, significant questions. Consequently, drilling of each hole should be preceded and accompanied by extensive geophysical studies, using all the new tools that have become available during the last few years—multi-channel seismic arrays, bottom-towed side-scanning instruments, and the rest. But as our drill bits penetrate deeper into the earth, we should also expect the unexpected. In this sense, future drilling must be thought of as exploration into the unknown as well as a process of question-answering.

Many of the most remarkable results of the last ten years of deep sea drilling were unexpected surprises. Consider, for example, the vast salt deposits underlying the Mediterranean, the black shales of Cretaceous age in both the Atlantic and the Pacific, the extensive layers of chert in the Paleogene sediments, the hydrothermal mounds of the Galapagos spreading center, and the unexpectedly great age of the Antarctic Ice Cap.

Alfred North Whitehead once said "the universe is not only strange, but it is stranger than we can imagine." A long lifetime in the earth sciences has convinced me that this wise statement applies to the earth beneath our feet as well as to the starry universe above us. The earth is full of wonders. We may not be able to imagine these until we see them, but by careful observation and clear-headed reasoning it should be possible for us to understand them. This is the underlying justification for a continuing program of exploration of the earth beneath the sea, with the powerful drilling tools we have learned to use so well. ■

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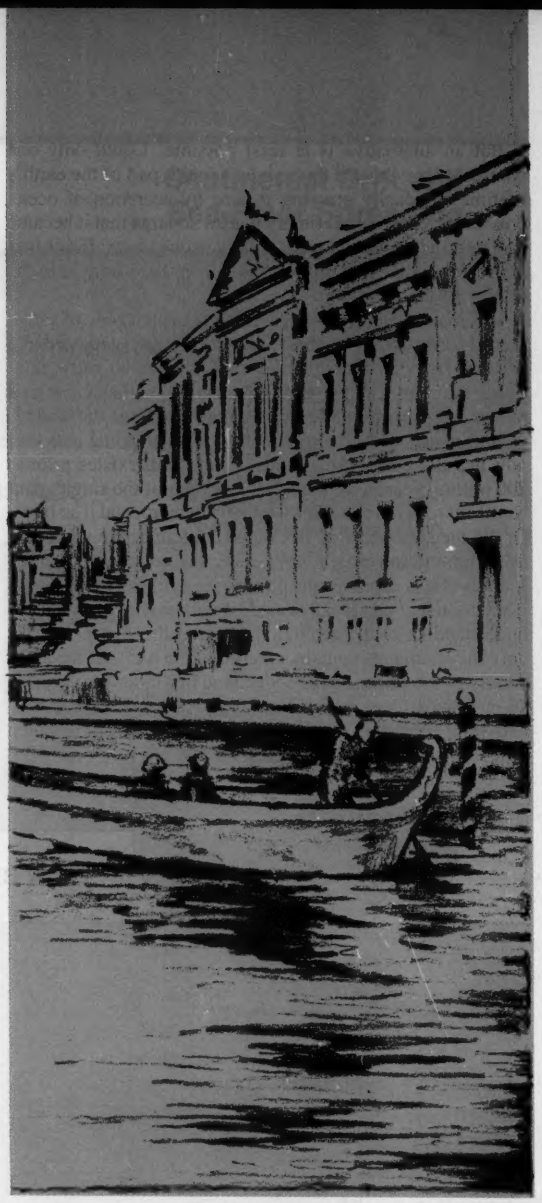
# Events, Deeds & Deliberations



### Venice Is On The Rebound

Venice has not only stopped sinking, but has actually risen slightly, a group of Italian scientists have concluded following several years of observations and laboratory testing. Dr. Paolo Gatto, a geologist at the state-run National Research Council, says measurements taken over the past seven years indicate that water pressure has built up again under the canal city and halted the sinking process.

As recently as 1970, the city was sinking at a rate of 0.2 inch per year, but refilling of the underground water table has reportedly caused a rebound of about 0.4 inch. This refilling is said to have been brought about by capping most of the artesian wells from which nearby industries had been withdrawing excessive amounts of water. In addition, the air has gotten cleaner, thanks largely to conversion from sulfur-contaminated fuel oil to natural gas for heating. But the high tides that sweep in twice a day from the Adriatic Sea remain a threat, and officials and scientists are still searching for a solution to this problem. *(Water Resources Bulletin)*

### Fish and Wildlife Service Uses West Virginia Solar Energy System

One of the world's largest space heating and cooling solar energy systems is harnessing the sun's power amid the hills of West Virginia to fuel the new home of the U.S. Fish and Wildlife Service's National Fish Health Research Laboratory at Leetown.

This new solar unit is part of a larger, highly-sophisticated energy system based on the overall rise and fall of heat within the building. This system extracts and recirculates "waste" heat in a process popularly called "heat scavenging."

When the solar system is in full operation, it will provide as much as 60 percent of the lab's space heating and cooling needs, backed up by a conventional oil-fueled boiler and the lab's 55 degree spring water source that stays at a constant temperature all year.

By combining solar energy and heat scavenging into an integrated energy system at the center for the study of fish health and fish culture, the Interior Department and the Federal government hope this project will serve as a model to demonstrate the practicality of solar power and energy reclamation.

### Soil Conservation Society Elects

Gerald R. Calhoun of College Park, Maryland, became President of the Soil Conservation Society of America on January 1.

Calhoun is state conservationist for the U.S. Soil Conservation Service (SCS) in Maryland. Joining Calhoun on the Society's Executive Committee this year will be President-elect Jesse L. Hicks, state conservationist for SCS, Raleigh, North Carolina; Vice-president Robert C. Baum, Pacific Regional Representative for the National Association of Conservation Districts, Salem, Oregon; Second Vice-president Chris J. Johannsen, extension agronomy specialist, University of Missouri, Columbia; and Treasurer H. Lynn Horak, vice-president and manager of the bond investment department, Iowa-Des Moines National Bank, Des Moines, Iowa ■

# Coming Events

45th North American Wildlife and Natural Resources Conference at Miami Beach, Florida, March 22-23.

7th Energy Technology Conference and Exposition at Washington, D.C., March 24-26.

International Symposium on Fishery Resources Allocation at Vichy, France, April 20-24.

14th International Symposium on Remote Sensing of Environment, San Jose, Costa Rica, April 23-30.

Symposium on Water & Related Land Resource Systems at Case Western Reserve University, Cleveland, Ohio, May 28-31.

16th American Water Resources Conference at Minneapolis, Minnesota, October 12-16 ■

# Bookshelf

**American Rivers—A Natural History,** by Bill Thomas, is a photographic tour of U.S. rivers across the breadth of the nation. In a 221-page coffee-table size book, the author mixes an eye for detail with a grasp of riverine history that makes this publication informative as well as beautiful. More than 250 full-color photos illustrate the $30 volume, available from W. W. Norton, Inc., 500 Fifth Ave., N.Y., N.Y. 10036 ■

**Fish and Wildlife Protection in the Planning and Construction of the Trans-Alaska Pipeline** is an appraisal of how well biologists were brought into the decisionmaking process and how much heed was paid to their recommendations by the architects of the 800-mile Trans-Alaska Pipeline. Copies available for $3.25 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock Number 024-010-00470-3) ■

**The National Wetlands Newsletter** provides government officials, planners and managers, scientists, attorneys, conservation groups and others concerned with wetlands and floodplain management a forum for exchanging ideas, information and problems. Available from the Environmental Institute, 1346 Connecticut Ave., NW, Washington, DC 20036 ■

# Changes of Command

Major General Harry A. Griffith has succeeded Major General Louis W. Prentiss as division engineer for the U.S. Army Corps of Engineers' Ohio River Division in Cincinnati. Griffith had been serving as chief of the Joint U.S. Military Assistance Group in Korea since May 1977. Prentiss, Ohio River division engineer since August 1978, was reassigned as commander of the U.S. Army Training Center and Ft. Leonard Wood, Missouri.

Major General Joseph K. Bratton has been assigned as division engineer for the U.S. Army Corps of Engineers' South Atlantic Division in Atlanta, Georgia. Bratton was serving as director of military application for the Department of Energy in Gaithersburg, Maryland. He succeeded Brigadier General Kenneth E. McIntyre who retired from military service.

Colonel Louis J. Circeo, Jr., is the new director of the U.S. Army Corps of Engineers' Construction Engineering Research Laboratory in Champaign, Illinois. He succeeds Colonel James E. Hays, who has been reassigned to the U.S. Army Materiel Development and Readiness Command in Alexandria, Virginia, as director of installations and services. Circeo was formerly a staff officer in the Nuclear Plans Section at the Supreme Headquarters of Allied Powers Europe, in Belgium.

Colonel Maximilian Imhoff has assumed duties as the first commander and director of the Water Resources Support Center at Fort Belvoir, Virginia. He was formerly the executive director of the Civil Works Directorate, Office of the Chief of Engineers ■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*The Japanese are among world leaders in commercial marine fishing and its burgeoning corollary—ocean habitat development and enhancement. See "Fisheries Development: Japan" on Page 1.* (Photo by Dan Sheehy)